Laboratory Environment Safety and Health Committee
Cryogenic Safety Subcommittee

MINUTES OF MEETING 03-05

August 4, 2003

FINAL

Committee Members Present	**Committee Members Absent**
M. Gaffney	P. Mortazavi
W. Glenn	J. Muratore
M. Iarocci	
S. Kane	
P. Kroon	
E. Lessard (Chairperson)	
M. Rehak	
R. Travis* (Secretary)	
K. C. Wu	
N. Bernholc+	
R. Gill	
P. Williams	
(* Non-Voting Member, + Ad Hoc Member)	

Visitors

A. Ackerman	M. Lowry
C. Bade	A. Sandorfi
D. Healy ++	C. Winter++
N. Gmur	
(++ Via Videoconferencing Link)	

Agenda:

1. **Review of the Physics Department LEGS In-Beam Cryostat Replacement**

Minutes of Meeting: Appended on pages 2 through 5.

ESH COMMITTEE MINUTES APPROVED:

Signature on File
E. Lessard
LESHC Chairperson

DM2120.

Chairperson E. Lessard called the fifth meeting in 2003 of the Laboratory Environmental Safety and Health Committee (LESHC) to order on August 4, 2003 at 2:10 p.m.

1. **Review of LEGS In-Beam Cryostat:** E. Lessard invited C. Winter to present the proposed replacement of the Laser Electron Gamma Source (LEGS) In-beam Cryostat located in the National Synchrotron Light Source LEGS Target Room (Room 168 of Building 725). Mr. Winter is associated with Quantum Technology, the cryostat vendor. His presentation is included in the web version of these minutes. The material that was reviewed by the Subcommittee in preparation for this meeting is also attached to the web version of these minutes. The 03-05 minutes are posted at: http://www.rhichome.bnl.gov/AGS/Accel/SND/past_leshc_business.htm. Presentations and submitted documentation were listed as attachments and were bookmarked within the PDF file for the web based 03-05 minutes.
   1.1. Mr. Winter and other attendees made the following points during the course of the presentation and in response to specific Committee questions:
      1.1.1. The proposed in-beam cryostat replaces an existing unit that is located in the LEGS Target Room in the NSLS.
      1.1.2. Static magnetic field discussion:
         1.1.2.1. The calculated static magnetic field 5 and 600 gauss lines are plotted on a drawing contained in Appendix 1. The 600 gauss line is contained within the cryostat apparatus. The 5 gauss field line is entirely enclosed within the associated experimental structure. Physical contact is not possible.
         1.1.2.2. The BNL Static Magnetic Field Subject Area requires specific postings if the magnetic field exceeds 5 gauss. Room 168 is already posted with these signs.
      1.1.3. In-beam Cryostat mylar window discussion:
         1.1.3.1. A design lifetime for the In-beam Cryostat mylar window is not specified, however, the window is similar in design to those in use at LEGS since 1990.
         1.1.3.2. Quantum Technology is not aware of any window failures in any of its products.
         1.1.3.3. A window failure will cause the loss of the insulating vacuum space in the cryostat. The liquid helium inventory in the cryostat will boil off in approximately 5 seconds. The 3-gram solid hydrogen target will sublimate. The energy of combustion is small, however.
         1.1.3.4. Since the window is in a gamma ray beam (10^7 photons/second), radiation damage is negligible. Vacuum forces predominate.
         1.1.3.5. Based on visual inspection Quantum Technology chose the best window for cryostat installation. The second-best window was tested to failure. It ruptured at approximately 150 psi, resulting in a safety factor of ~ 7.
         1.1.3.6. The Committee noted that Kevlar-mylar windows have catastrophically failed at the Alternating Gradient Synchrotron (AGS) before the design end-of-life. The failures were attributed to how the windows were fixed at the edges rather than overstress.

1.1.3.7. E. Lessard believes that a graph of time vs. stress for the AGS windows is available. He volunteered to try to locate that information and provide it to the Physics Department. - **Complete**[1], See http://accelconf.web.cern.ch/accel_conf/pac97/papers/pdf/4P002.PDF

1.1.4. The solid hydrogen target is produced in another cryostat and polarized. The polarized target is transported to the LEGS room in a transfer cryostat with integral permanent and superconducting magnets.

1.1.5. Oxygen Deficiency Hazard (ODH) discussion:

1.1.5.1. An ODH analysis was performed in 1999 for the present LEGS installation. It was distributed at the meeting and is included in the web version of these minutes.

1.1.5.2. The calculation does not consider the additional 45 liters of liquid helium contained in the In-beam Cryostat.

1.1.5.3. The analysis predates the current BNL ODH requirements. It is appropriate to review the SBMS ODH Subject Area (SA) and update the calculation (i.e., 545 liters of LHe, with and without the exhaust fans). The SA has additional requirements (such as postings and training) that must also be implemented.

1.1.6. Electrical equipment discussion:

1.1.6.1. Several electrical components, such as the superconducting magnet power supply, are custom built.

1.1.6.2. Quantum Technology certifies that this equipment meets North American (Canadian) Electrical Codes.

1.1.6.3. Quantum was requested to certify that the electrical components conform to Underwriter's Laboratory (UL) Standards.

1.1.7. Pressure vessel discussion:

1.1.7.1. Quantum Technology stated that the In-beam Cryostat pressure vessels are not required to be ASME coded.

1.1.7.2. Information on the construction of the various vessels was verbally provided during the meeting.

1.1.7.3. The Committee requested additional information for these vessels and noted that the BNL requirements for experimental pressure vessels are contained in Environmental Safety and Health Standard, ESH 1.4.1.

1.2. The following motions were crafted by the Committee:

1.2.1. Motion No. 1 - Prior to performing LEGS In-Beam Cryostat commissioning activities, the Physics Department must:

1.2.1.1. Ensure that all personnel that are involved in the commissioning process (including the Quantum Design representative) take the BNL "Cryogen Safety", "Oxygen Deficiency Hazard" and "Static Magnet Field" training courses at http://training.bnl.gov/.

1.2.1.2. Review the SBMS Subject Area "Oxygen Deficiency Hazards (ODH), System Classification and Controls" https://sbms.bnl.gov/standard/16/1600t011.htm, and perform the ODH

[1] This action item was completed during the review cycle for these minutes.

calculations, both with and without the exhaust fans. Implement the appropriate control measures. Submit the calculations and the proposed control measures to the LESHC Cryogenic Subcommittee for review.

1.2.1.3. Perform a quench test to assure that the magnet vessel will not fail. Provide the results of this test to the Committee.

1.2.1.4. Perform a calculation to compare the oxygen diffusion rate with the flow rate out of the LN2 vent. Provide this information to the Committee.

1.2.1.5. Provide a written certification to the Committee that the electrical components of the in beam cryostat conform to Underwriter's Laboratory (UL) standards.

1.2.1.6. Review BNL ESH Standards 1.4.1, "Pressurized Systems for Experimental Use" and 1.4.2, "Glass and Plastic Window Design for Pressure Vessels" and demonstrate compliance to the Committee.

1.2.1.7. Provide design details (including drawings) of the helium 3 still and the liquid helium pressure vessels for Committee review.

1.2.1.8. Provide a transfer procedure(s) for: refilling the LHe cryostat from the 500 liter transfer cryostat and the replenishment of the LN2 automatic refill system.

1.2.1.9. Address Committee comments on the "Operating Procedures for the BNL In-beam Cryostat". Provide the revised procedures for Committee review. (Please see Appendices 2 and 4 for the procedures and the Committee comments.)

1.2.2. Motion No. 2 – At the end of the commissioning process, but prior to the start of the LEGS In-Beam Cryostat operations, the Physics Department must:

1.2.2.1. Implement Conditions 1.2.1.1 and 1.2.1.2, as appropriate for LEGS In-beam Cryostat operation.

1.2.2.2. Refer to the "Static Magnetic Field" Subject Area at https://sbms.bnl.gov/standard/1u/1u00t011.htm. Based on actual magnetic field strength measurements, implement the appropriate requirements.

1.2.2.3. Verify compliance with the Static Magnetic Field SA for the hydrogen target transfer cryostat.

1.2.3. M. Gaffney made a recommendation for approval of the Motions.

1.2.4. Seconded by W. Glenn.

1.2.5. The motions were approved by vote of 11 in favor and none opposed.

2. The Meeting was adjourned at 3:50 p.m.

3. Addendum to the Minutes

3.1. The purpose of this addendum is to document the salient points of the Committee discussions and emails that occurred after the 8/4/03 meeting.

3.1.1. NSLS has agreed to perform ODH analyses for dewar transport and temporary storage areas for all experimental activities at their facility in conformance with the ODH Subject Area. The NSLS analysis is outside the purview of this LESHC meeting and follow-up is referred to the BNL Safety and Health Services Division.

LEGS CRYOSTAT SAFETY REVIEW 2003 July 31

Notes for safety review of Laser Electron Gamma Source (LEGS) Cryostat replacement:

1 REPLACEMENT CRYOSTAT

This is a safety review of a replacement cryostat to be used in Rm. 168 of Bldg. 725 (the LEGS target room). The device is very similar to an existing cryostat which passed previous safety reviews and has raised no safety concerns during the three years that it has been on site at BNL.

2 OVERVIEW OF CRYOSTAT:

Purpose - maintain a solid spin polarized HD target (0.03 liters)

Method:
Permanently evacuated (not pumped) vacuum insulated vessel with the following cooling systems:
a) Liquid nitrogen (77K) cooled shields
b) Liquid helium (4.5K) cooled shields
c) Pumped liquid helium (2K) cooled superconducting magnet (1T)
d) Pumped liquid helium (1.5K) heat exchange bath to condense helium-3 mix.
e) Still to evaporate helium-3 mix (0.8K)
f) Dilution refrigerator where helium-3 rich fluid mixed with helium-4 rich fluid (0.2K)

Helium-4 boil-off from the main helium bath and the 2K and 1K pot pumps is normally recovered to an external helium recovery system (and liquefier).

Helium-3 mix is always below atmospheric pressure, it is circulated closed-cycle by a turbo-pump and hermetic vacuum pump.

Control system:
The system operates on a PLC on a UPS independent of computers. Operator interface to change parameters is through Labview software on an external computer.

3 POTENTIAL HAZARD IDENTIFIED:

3.1 Oxygen Deficiency Hazard (ODH): This will be operated in an experimental area which has already been approved by the safety review committee for a 500 liter liquid helium transport dewar. The volume of the experimental area is 27,000 cubic feet. This experimental area is equipped with exhaust fans on emergency power.

The volume of liquid helium stored in the cryostat is only 45 liters. After expansion to room temperature 45 liters of liquid helium x 750/28.3 = 1,200 cubic feet of helium gas, which is less than 5% of the volume of the room (could reduce 21% O2 to 20%). This volume of helium would be safe in this room even without ventilation according to the BNL ODH rules (19.5% mininum O2).

The main potential ODH in room 168 is associated with helium transfers and with a *storage* cryostat. Nonetheless, these have already been approved by a safety committee based on the ventilation in the room.

The volume of liquid nitrogen stored in the cryostat is only 5 liters. After expansion to room temperature 5 liters of liquid nitrogen x 646/ 28.3 = 114 cubic feet of nitrogen gas, which is less than 1% of the volume of the room.

3.2 Physical layout: Please see drawing DRLayout_2.dwg

3.3 Piping and instrument drawing: Please see drawing: Block_35.dwg

3.4 Design Parameters:

- Maximum design/Allowable working pressures:
  - Cryostat outer vacuum vessel (stainless steel)
    - Operating pressure: vacuum
    - Relief port: 25mm diameter vented to a 2" OD pipe for connection to a 350 cfm fan which is on emergency power.
    - Relief port pressure setting: 0 (gravity operated)
    - Volume of vacuum vessel is: 230 litres
    - Volume of vacuum = 230 liters - 45L LHe - 5L LN2 = 180 liters
    - ASME code safe internal working pressure approx: 87psig
  - Liquid nitrogen vessel (stainless steel)
    - Operating pressure: atmospheric
    - Vented to atmosphere
    - Volume approximately 5 litres
    - ASME code safe internal working pressure approx: 92psig
  - Liquid helium vessel (stainless steel)
    - Volume approx. 45litres
    - Operating pressure: 2 psig
    - Normal Vented through recovery system
    - Safety relief vent to room: 2.35 sq.in. orifice set pressure < 5psig.
    - ASME code safe internal working pressure approx: 92psig
  - 2K pot helium vessel (copper)
    - Volume approx. 1/2 liter
    - Relief valve: 1/2 diameter (0.4" diameter orifice)

ASME code safe internal working pressure >100 psi

1K pot helium vessel (copper)
Volume approx 1/2 liter
Relief valve: 1/4 diameter pipe (0.2" diameter orifice)
ASME code safe internal working pressure >100psi

He-3 mix volume (copper) Still
Volume approx 1/3 liter (total volume of mix ~200 atm. liters)
Relief valve: 1/4 diameter pipe (0.2" diameter orifice) set at 5psig
Total volume of pumping tube = 100 liters
(so maximum pressure is 200atm.liters/100liters = 2 absolute atmospheres = 15psig)
Note in the event of a power failure the He-3 gas will bypass the hermetic pump and return to the dump tank as long as the valves are left open (normal operating mode).

3.5 Power failure:

System designed and tested to withstand power failures.
Superconducting magnet is powered by a very low voltage power supply rated at 100A and 3V.

3.6 LN2 trap plugging:

He-3 will return to dump tanks.
The LN2 traps are commercial devices from Oxford Instruments and are equipped with 30psi relief valves.

3.7 Potential for a combustion of hydrogen:

The volume of the target is 25 cm^3 which corresponds to 3 grams of HD.
The total energy of combustion is similar to burning 1 tablespoon of gasoline.
Hydrogen burns with an almost invisible flame to produce water.
The net heat of combustion is 120kJ/gram for hydrogen (about 80kJ/gm for HD). The total energy released by combustion of the target would thus be 80kJ/gm x 3 gm = 240kJ.
For hydrogen the lower flammable limit is 4% in air.
The lower explosive limit is 18% in air.

It is difficult to construct a scenario which would result in ignition of the hydrogen before it would be so diluted with air that it would not ignite.

For example, if the mylar window breaks then air rushing past the target will evaporate it to make 22 litres of HD gas mixed with 180 litres of air. In the first instant this would be 12% hydrogen, or still a flammable mixture. Air will continue to flow slowly into the cryostat, condensing on the liquid helium cooled surfaces. This will soon dilute the mixture to below the flammable threshold. Even if there was ignition the heat would be mainly dissipated inside the cryostat resulting in an insignificant (~1K) increase in average cryostat temperature.

In another example, suppose that someone removes the blankoff port and opens the vacuum pumpout valve on the main cryostat. In this case the cryostat will fill from air from the other end, causing the target to evaporate. In this case there will be a hydrogen rich region in the target snout end, however again ignition is unlikely.

The natural concern with hydrogen is the "pop" small explosion which can occur when an appropriate mixture of hydrogen and air is ignited. However, in our case the amount of hydrogen is so small that even if this were to occur after the cryostat vacuum vessel was filled with air and somehow be so well mixed that the entire volume could participate in the explosion, the internal pressure would only rise (instantaneously) to 84psi. This is within the design pressure of the vacuum vessel so the vacuum vessel would not break, and the hot air would be exhausted out the relief port (and possibly out the snout mylar window).

The principal hazard to personnel is the potential for hearing damage due to the loud pop. Given the small size of this target, the distance to personnel and lack of ignition sources we consider this risk of hearing damage in the event of an explosion to be very low and risk of a "pop" to be remote.

High pressure on cold-cathode gauge triggers alarm through PLC program.

Thermocouple gauge is interlocked to switch off high voltage supplies to detectors.

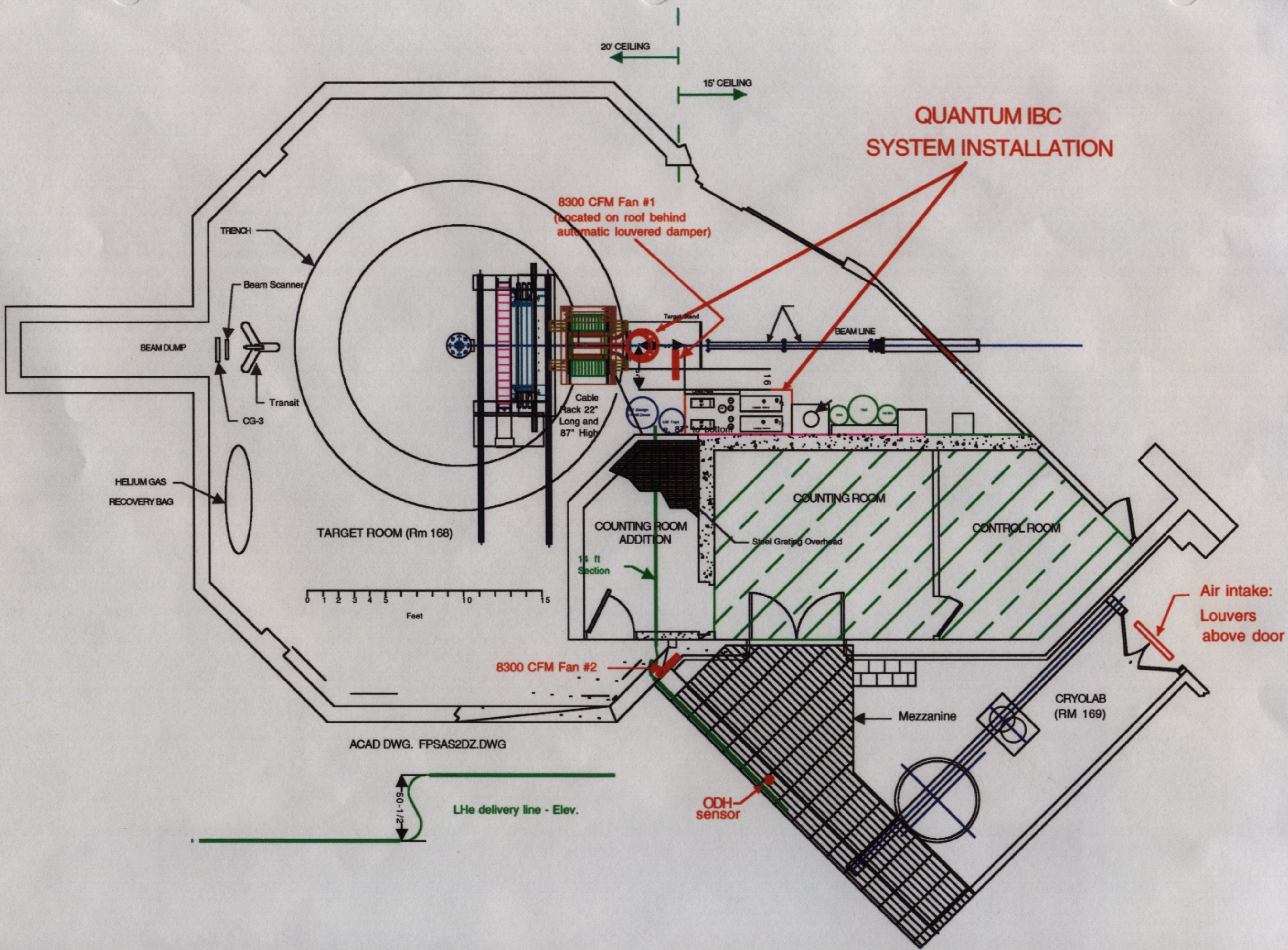
3.8 Quench protection:
The system includes a very small superconducting magnet operating at 100A and 0.1 H so the stored energy is 500Joules. This will cause a temperature rise of the coil from 2.K to 4K.

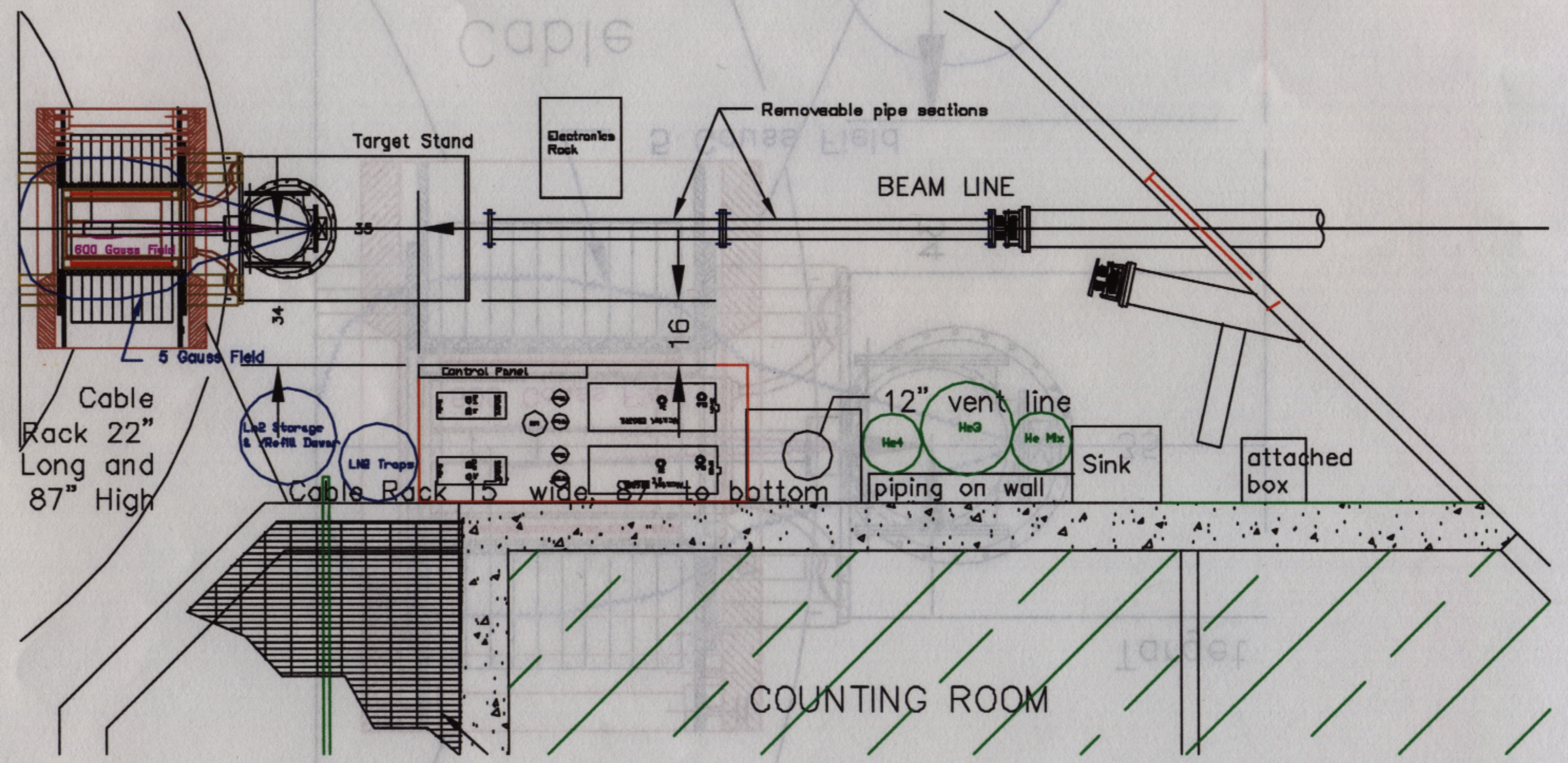
3.9 Electrical equipment:
Industry standard equipment, Agilent digital voltmeter, power supply, pressure and temperature sensors, vacuum pumps are used. The custom superconducting magnet power (3V 100A) supply has been built using rated components to industry standard. The control rack has been built to industry standard and is fully enclosed in a grounded metal case. Quantum Technology Corp. certifies that this equipment meets North American electrical codes.

4.0 Static Magnetic Field
The 60mm diameter (2.3") solenoid field is 1T, 250mm (10") long.
We have reviewed BNL's Static Magnetic Field Standard. We provided 5 Gauss line and 600 Gauss line contour plots on the physical layout drawing.

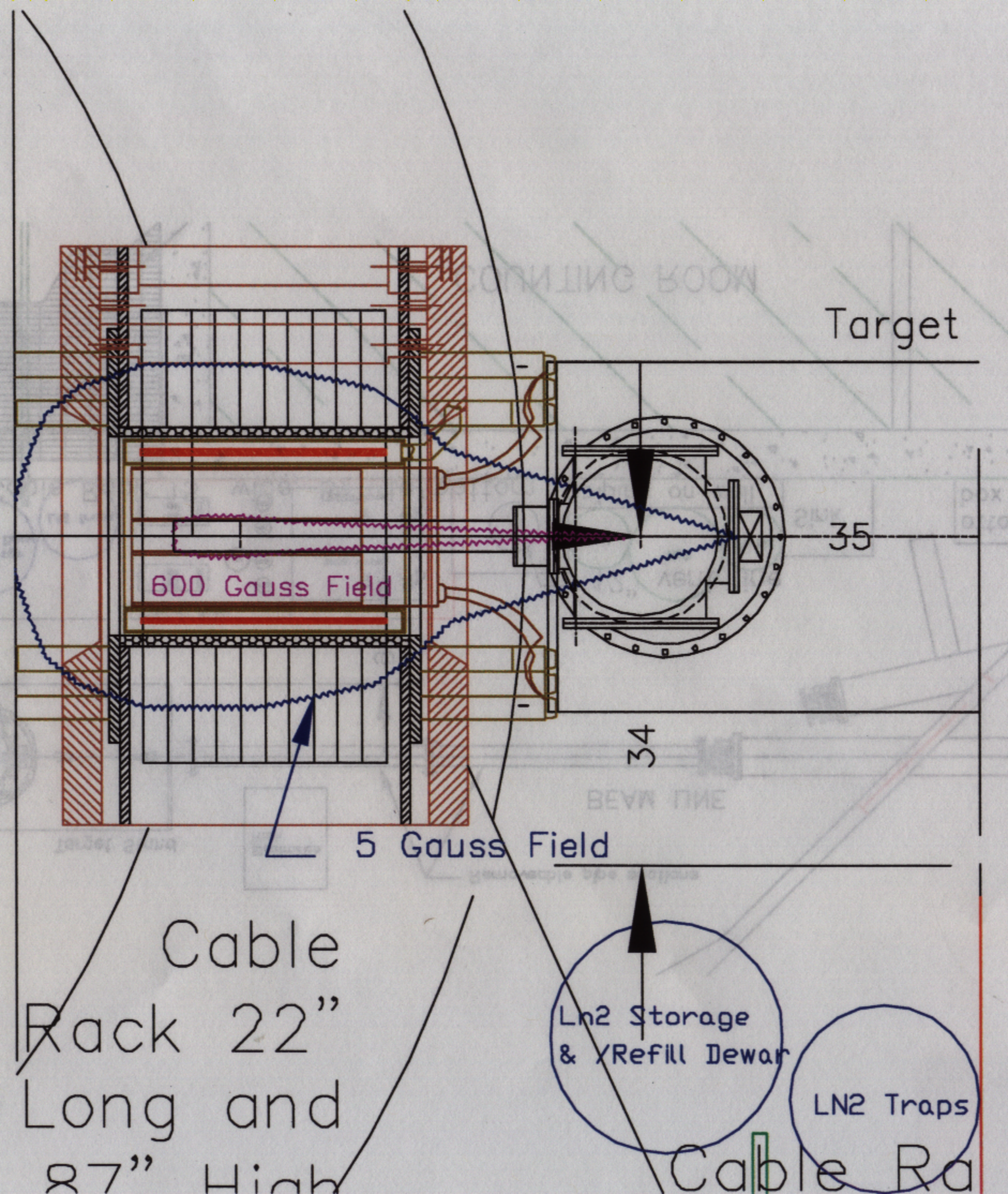
This cryostat will require Sign # 1 - Safety Sign External field. It will also require following BNL guidelines re: medical electronic devices (eg. cardiac pacemakers). The LEGS target room (Rm. 168 in Bldg. 725) is already posted as such.

The 600G field is essentially confined within the apparatus. The 5G field is generally within the area of cryostat and detectors. Please see contour plot.


QUANTUM IBC
SYSTEM INSTALLATION
20' CEILING
15' CEILING
8300 CFM Fan #1
(Located on roof behind
automatic louvered damper)
TRENCH
Beam Scanner
BEAM DUMP
Transit
CG-3
Target Stand
BEAM LINE
Cable
Rack 22"
Long and
87" High
87" to bottom
HELIUM GAS
RECOVERY BAG
TARGET ROOM (Rm 168)
COUNTING ROOM
ADDITION
COUNTING ROOM
CONTROL ROOM
Steel Grating Overhead
14 ft
Section
Feet
Air intake:
Louvers
above door
8300 CFM Fan #2
CRYOLAB
(RM 169)
Mezzanine
ACAD DWG. FPSAS2DZ.DWG
50-1/2"
LHe delivery line - Elev.
ODH
sensor



Removeable pipe sections
Target Stand
Electronics Rack
BEAM LINE
35
600 Gauss Field
34
16
5 Gauss Field
Control Panel
Cable Rack 22" Long and 87" High
LN2 Storage & Refill Dewar
LN2 Traps
12" vent line
He4
He3
He Mix
Sink
attached box
piping on wall
Cable Rack 15" wide, 87" to bottom
COUNTING ROOM



Target
35
34
600 Gauss Field
5 Gauss Field
Cable
Rack 22”
Long and
87” High
Ln2 Storage
& Refill Dewar
LN2 Traps
Cable Ra

Liquid Helium Vessel

1. Specifications

Vessel Diameter $D := 15.375 \cdot in$

Inner pipe diameter $d := 3 \cdot in$

Height $h := 15.313 \cdot in$

Volume $V := \frac{\pi}{4} \cdot \left(D^2 - d^2\right) \cdot h$

$V = 44.815\,\text{liter}$

Wall thickness $w := 0.0625 \cdot in$

2. Strength of the vessel

UTS for stainless steel $ult := 5 \cdot 10^4 \cdot psi$

Hoop stress rupture pressure $P_{hs} := \frac{2 \cdot ult \cdot w}{D}$

$P_{hs} = 406.504\,psi$

Weld thickness for end plates (fusion weld) $t_w := 0.025 \cdot in$

End plate blow off pressure $P_{end} := \frac{4 \cdot ult \cdot t_w}{D}$

$P_{end} = 325.203\,psi$

The ASME code requires a safety factor of 3.5, so the design pressure of the vessel is approximately

$\frac{P_{end}}{3.5} = 92.915\,psi$

3. Boiling of helium in case of loss of insulation vacuum

Surface heat flow rate $Q_f := 4 \cdot \frac{W}{cm^2}$

Helium vessel surface area $A := \frac{\pi \cdot \left(D^2 - d^2\right)}{2} + \pi (D + d) \cdot h$

$A = 0.801\,m^2$

Helium bath heating rate $\quad Q := Q_f \cdot A$

$Q = 3.203 \times 10^4\,W$

Latent heat of boiling for helium $\quad L := 20 \cdot \frac{joule}{gm}$

Density of helium $\quad \rho := 125 \cdot \frac{gm}{liter}$

Boiling rate $\quad B_r := \frac{Q}{L}$

$B_r = 1.601\,\frac{kg}{s}$

by volume, boiling rate $\quad B_{rv} := \frac{B_r}{\rho}$

$B_{rv} = 12.812\,\frac{liter}{s}$

Gas evolution velocity through 2" dia vent pipe

gas density $\quad \rho_g := \frac{\rho}{10}$

of 2.3 square inches. The flow rate through this valve is

$$v := \frac{B_r}{2.3 \cdot in^2 \cdot \rho_g}$$

$$v = 86.341\,\frac{m}{s}$$

and the corresponding pressure drop is

$$\Delta P := \frac{1}{2} \cdot \rho_g \cdot v^2$$

$$\Delta P = 6.758\,psi$$

The relief valve opens at 5 psi, so the pressure seen in the helium vessel is

$$P_{vessel} := 5 \cdot psi + \Delta P$$

$$P_{vessel} = 11.758\,psi$$

psi.

Nitrogen vessel

1. Specifications

Outer diameter $OD_N := 11.88 \cdot in$

Inner diameter $ID_N := 4.5 \cdot in$

Height $H_N := 3 \cdot in$

Volume $V_N := \frac{\pi}{4}\left(OD_N{}^2 - ID_N{}^2\right) \cdot H_N$

$V_N = 4.667\,\text{liter}$

Size of vent pipe $ID_{vp} := 0.87 \cdot in$

2. Boiling of nitrogen in case of loss of insulation vacuum

Latent heat of vapourization $L_N := 161 \cdot \frac{joule}{cm^3}$

Surface area of vessel $A := \frac{\pi \cdot \left(OD_N{}^2 - ID_N{}^2\right)}{2} + \pi\left(OD_N + ID_N\right) \cdot h$

Heat load $Q_N := A \cdot Q_f$

$Q_N = 2.524 \times 10^4\,W$

Boiling rate $R_N := \frac{Q_N}{L_N}$

$R_N = 0.157\,\frac{liter}{s}$

Time to empty $t := \frac{V_N}{R_N}$

$t = 29.778\,s$

Liquid density $\rho_L := 800 \cdot \frac{gm}{liter}$

Gas density at 77 K $\rho_G := 4.4 \cdot \frac{gm}{liter}$

Gas escape velocity $v := \frac{4 \cdot R_N \cdot \rho_L}{\pi \cdot ID_{vp}{}^2 \cdot \rho_G}$

$$v = 74.307\,\frac{m}{s}$$

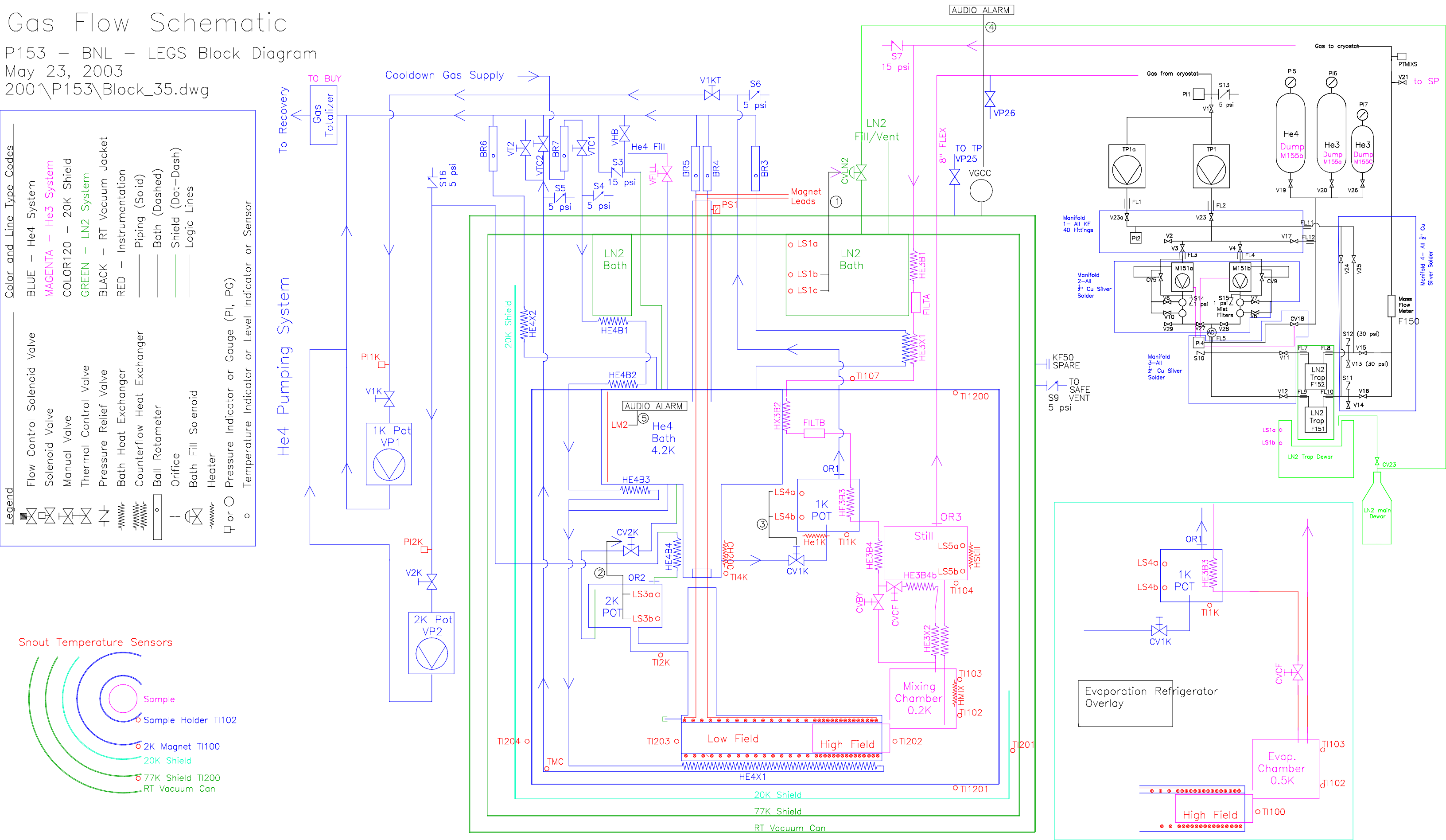
The correspnding pressure drop $\Delta P := \frac{1}{2}\cdot\rho_G\cdot v^2$

$$\Delta P = 1.762\,psi$$

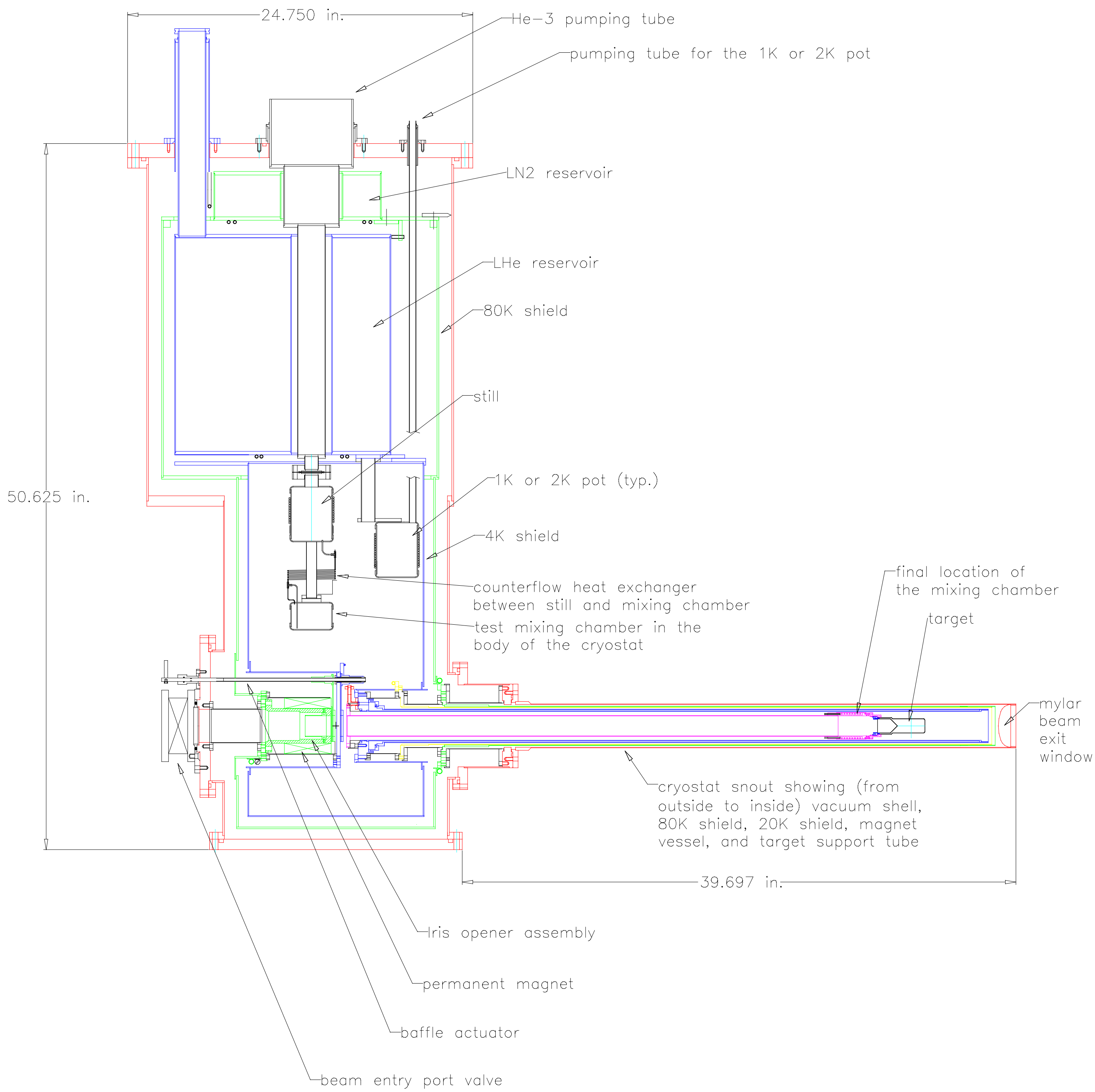
and this is the pressure expected to be seen inside the liquid nitrogen vessel

Gas Flow Schematic

P153 – BNL – LEGS Block Diagram
May 23, 2003
2001\P153\Block_35.dwg



In-Beam Cryostat Descriptive Drawing



GENERAL DESCRIPTION OF THE BNL IN-BEAM CRYOSTAT

Following is a general description of the in-beam cryostat, to be read in conjunction with the attached drawing labeled “In-Beam Cryostat Descriptive Drawing”.

The cryostat consists of an upright cylinder (approximately 50” high by 22” diameter) and a horizontal “snout” extension (approximately 40” long). The upright cylinder contains a liquid nitrogen reservoir (4 ½ liters) and a liquid helium reservoir (43 liters) with attached conduction cooled shields. Below the helium reservoir, and mechanically attached to the reservoir, are two pumped helium pots (the 1K and 2K pots) with pumping tubes extending up through the cryostat top plate. The 1K pot is the condensor for the dilution refrigerator and the 2K pot is the cooler for the magnet (which operates in superfluid).

A pumping tube (He-3 pumping tube) extends vertically down from the cryostat top plate and below this are attached the still, the tube in tube counterflow heat exchanger, and the mixing chamber of the dilution refrigerator. The mixing chamber is located as shown for the first test only, so that the refrigerator can be demonstrated to be working before the cooling is extended to the target at the end of the snout. This test is to be carried out without the Iris Opener assembly and the snout installed, these ports being simply blanked off.

After the first dilution refrigerator test has been successfully completed, then the rest of the IBC is assembled. The iris opener assembly and the snout assembly are put together outside the cryostat and then installed to the vertical portion of the cryostat by attachment to the upstream and downstream ports. Certain parts of the shielding around these elements have then to be assembled through two side ports at beam height level, and through the bottom port. Electrical and piping connections from the iris opener assembly and the snout assembly to the vertical portion of the cryostat are also made through these three access ports.

The snout consists of a set of concentric tubes. The outermost is the vacuum shell, closed at the downstream end with a domed mylar window. Inside this is an approximately 80 K shield, cooled by attachment to the 80 K shield in the main body of the cryostat. Next inside is an approximately 20 K shield cooled by a flow of cold gas from the LHe reservoir. Inside this is the double walled magnet vessel, filled with superfluid helium from the 2K bath. The magnet is wound on the inner wall of the magnet vessel. The innermost tube is the support tube for the annular mixing chamber, to which is attached the frozen HD target.

OPERATING PROCEDURES FOR THE BNL IN-BEAM CRYOSTAT

(revised May 19/03)

These instructions are referenced to the State Table (file P153dh_1b_state table.xls) and the gas flow system schematic (file BLOCK_35.dwg).

1.PRIOR TO COOL DOWN

This section describes the procedures that are necessary to establish the insulation vacuum in the cryostat and to purge and leak check the internal gas circuits in the cryostat. These procedures prepare the cryostat for the initial cooling.

1.1Check that all devices are correctly set as designated by the State Table, the column labeled “Prior to Step 1”.

1.2Evacuate target cryostat through valve VP25 using a portable turbo pump to 10-4 Torr, monitoring the visual dial gauge (for pressures between 760 Torr and approximately 10 Torr) and VGCC, (the cold cathode gauge). In addition, one should monitor any gauges that are mounted on the portable turbo stand.

1.3Check that no helium leak is present inside the cryostat (helium leak detector attached to turbo pump exhaust, helium detector sensitivity better than 10-8 atm cc/sec). The checking will occur automatically as the helium circuits are purged in the following sections. Leave the turbo pump and leak detector attached until the helium circuits have been checked.

1.4Purge the helium-4 reservoir. Evacuate the helium reservoir to about 10 Torr and back fill with helium to about 3 psig (the relief is set to about 5 psig) and maintain this pressure during the following operations. This evacuation and refill can be done through the transfer line port.

1.5Purge the helium-4 circuits. In sequence slightly open and leave open the flow meter valves BR3, BR4, BR5, and BR6 and ensure that flow exists. Leave the helium flowing for 5 minutes at a rate of about 1 liter/minute. Close BR3, BR4, BR5, and BR6 and leave the helium-4 reservoir pressurized at 3 psig.

1.6Purge the 1 K and 2 K Pots. Turn on the 1 K Pot and 2 K Pot pumps (VP1 and VP2) and open their associated valves (V1K and V2K). Open V1KT and CV1K and check the flow in the 1 K Pot (see the pressure rise in PI1K). Close V1KT and V1K . Open CV2K and check the flow in the 2 K Pot (see the pressure rise in PI2K). Close V2K. This will leave the 1 K Pot and the 2 K Pot pressurized to 3 psig. (Note: Allow 5 minutes for the thermal valves CV1K and CV2K to open.)

1.7Purge the cool down supply line. Attach 5 psig helium gas source to BR7 and open BR7.

1.7.1Attach the service pump to VT2 and turn if on. Open VT2 and evacuate the cool down line. Close VT2 and turn off and remove the service pump.

1.7.2Open VTC1 and VTC2 (to recovery). Check flow (BR7) and close BR7

1.8Preparing the refrigerator circuit

1.8.1Prepare the LN2 cooled gas cleaners (F151 and F152). Evacuate both traps using the service pump through valves V13 and V14 until a pressure of 30 microns is reached. Close V13 and V14.

1.8.2Open CVCF and CVBY. Evacuate the refrigerator with a mechanical pump via VP26 and V21 (connected together and teed to the mechanical pump via a separate service valve) to a pressure of less than 10E-1 Torr (PI1) and close the service valve once this pressure is reached, to avoid oil back streaming into the refrigerator. This leaves VP26 and V21 still open.

1.8.3Open V23 and evacuate the exhaust of the turbo pump with a mechanical pump via V2. When the mechanical pump pressure has dropped to less than 10E-1 Torr, open the gate valve V1 and turn of the turbo pump (TP1) to continue pumping on the refrigerator. This pumps on the return side of the refrigerator via VP26 and V21.

1.8.4Cool the gas cleaner F151 using the auto fill controller, checking this for proper operation. Let in pump gas by opening V12 and V28. Leave the cleaner to cool for 20 minutes.

1.8.5Turn on the rotary pump M151b.

1.8.6Close V2 and open V4 so now M151b is backing TP1.

1.8.7Close VP26 and V21

1.8.8Open V16 to let some helium into the refrigerator.

1.8.9Open V19 and then slowly open V17 to meter helium gas into the refrigerator to a pressure of 100 Torr as read by PI4, then close V17.

1.8.10Helium is now flowing slowly through the refrigerator. Check the function of the flow meter F150 and the pressure gauge PTMIXs by closing and opening V16.

1.8.11Close V16 and V1 and turn off TP1. Allow TP1 to stop and then close V4, and turn off M151b.

1.8.12Continue the LN2 auto fill of the LN2 trap F151.

This completes the purging, flow testing, and leak testing of all flow loops and the system is now ready for cool down. If there is any uncertainty, go back and recheck the system. A few minutes checking out at room temperature can save a day in preventing a faulty cool down.

2.COOLDOWN PROCEDURE

This section describes the procedures used to cool and fill the LN2 And LHe reservoirs. It also describes starting the flow through the refrigerator and through the 1K and 2K pots to start cooling these elements. External helium gas flows through the circuit which cools the magnet enclosure and the target support tube.

2.1Fill the cryostat LN2 reservoir using the auto fill system and check the operation of this system. Wait 1-2 hours to allow shields to cool.

2.2Close the vacuum pumping port VP25. Remove the leak detector and the turbo pump.

2.3Turn on the mechanical circulation pump (M151b) and open V1, V4, and V16 to start helium flowing through the refrigerator. Turn on the turbo pump TP1. This flow will start cooling the refrigerator as the rest of the cryostat cools. Maintain PI4 at about 100 Torr using V17 to admit gas.

2.4Start a helium transfer in the cold gas flow mode.

2.4.1Do not transfer any liquid at this stage. It is preferable to use a slow flow of cold gas directed right to the bottom of the reservoir for a long time - about 6 hours - to cool the cryostat. Putting in more liquid can waste a huge amount of liquid helium and will not appreciably shorten the cool down time (which is limited by thermal diffusion time constants).

2.4.2This slow cold gas transfer mode is effected by throttling the exit helium flows and connecting a very small overpressure to the helium supply vessel.

2.4.3To do this set the valves BR4 and BR5 to ½ turn open and BR3, BR6 and BR7 each to 1 turn open. Pressurize the helium source vessel to 3psig (0.2 bar). The desired total flow rate during this phase is 3 liquid liters per hour (40 gas liters per minute). Adjust BR3, BR4, BR5, BR6, and BR7 to achieve this rate, monitoring the gas totalizer.

2.4.4Open V1K and V2K each ½ turn, reducing the flow through the 5 valves above to maintain a flow rate of 3 liquid liters/hr. This will start cooling the 1 K Pot and the 2 K Pot.

2.5Once the helium-4 reservoir is below 40K for 1 hour it is possible to fill the reservoir with liquid. This is done by fully opening all flow control valves BR3, BR4, BR5, BR6 and BR7. Open Ball Valve VHB to allow a large gas flow. Monitor the liquid helium level gauge. The desired transfer rate is 1 liquid liter per minute. Initially this will cause a gas flow rate of 750 gas liters/minute, but as liquid begins to accumulate in the reservoir, this rate will drop. About 40 minutes is required for the transfer. Adjust the liquid supply dewar pressure as necessary to achieve this. Again monitor the flow rate using the gas totalizer.

If liquid fails to accumulate after 15 minutes close the ball valve VHB and continue with cold gas flow cooling for 1 hour. Then open VHB and repeat the liquid transfer procedure.

2.6Once the liquid helium reservoir is full as shown on the superconducting liquid helium level gauge LM2, then vent the LHe supply cryostat to stop the transfer. Close VFILL and disconnect the flex section of the transfer line, removing it from the source dewar. Slowly close the VHB ball valve, monitoring the bath pressure which should not rise above 5 psi.

3. AFTER THE LIQUID HELIUM RESERVOIR IS FULL

This section describes cooling the 1K and 2K pots to their operating points, and cooling the mixing chamber and its support tube to about 10K.

3.1 Wait 1 hour to allow the liquid helium shields to cool. Continue to monitor and plot the gas totalizer readings – this provides an excellent insight into the efficiency and progress of the cool down.

3.2 As the 1 K Pot starts to fill with liquid helium the flow through the needle valve CV1K will become excessive (PI1K too high). Switch CV1K to automatic control. The automatic control (PLC) uses sensors PI1K and LS4a and LS4b to monitor the 1 K Pot cool down and closes the valve CV1K gradually to prevent excessive flow and once liquid accumulates in the 1 K pot, maintains the level of liquid between the two level sensors. Fully open V1K.

3.3 Similarly, the 2 K Pot flow control valve (CV2K) should be switched to automatic. Fully open V2K.

3.4 Similarly, switch the circulation flow control valve to automatic. The PLC will keep CVBY wide open until flow becomes excessive (monitoring PI1). It will then gradually close CVBY. Once the mixing chamber temperature reaches below 2K, the PLC will close CVBY and the entire flow will pass through CVCF.

3.5 Once the mixing chamber has reached 10 K, the cool down gas flow should be stopped (close valves VTC1 and VTC2) and evacuated . To evacuate, connect the service turbo pump, and pump through VT2 for 5 minutes to reach below 10 microns, then seal it off by closing VT2. The timing of this operation is perhaps the only thing which is a little critical. If it is done too early the target support tube will be left warm (> 50K) and will take many hours to cool.

4. FINAL COOLING OF THE MAGNET

This section describes the final cooling and filling of the magnet housing.

4.1 At this point, the magnet 2 K Pot has been cooled by helium flow through CV2K to about 2 K and the magnet housing has been cooled to about 10 K by the cool down gas flow. In addition, the cool down gas flow has been stopped and the cool down pipe evacuated, and the automatic liquid level control in the 2 K Pot has been actuated. Further cooling will proceed by superfluid liquid progressing down the copper tube to the magnet housing and then cooling that housing to about 2 K. This will occur automatically.

5. COOLING THE REFRIGERATOR TO THE OPERATING TEMPERATURE

This section describes filling the refrigerator with its operating mixture of He-3 and He-4 from the storage reservoirs in the pump stand, and bringing the refrigerator to its operating temperature.

5.1 By this point, the liquid nitrogen and liquid helium reservoirs have been filled, the magnet bath has been cooled to about 2 K, and the mixing chamber has been cooled to about 2 K. Helium gas is slowly circulating through the refrigerator.

5.2 Slowly open V17 to meter helium-4 gas into the system, maintaining a condensing pressure of less than 500 Torr (PI4) until the He-4 Dump pressure drops to a predetermined value (PI5), and then close V17 and V19.

5.3 Open V20 and slowly open V17 to meter helium-3 gas into the system, maintaining a condensing pressure of less than 500 Torr (PI4) until the He-3 Dump pressure drops to a predetermined value (PI6), and then close V17.

5.4 Once the fluid has been condensed to the mixing chamber and the still, tune the refrigerator for the desired low temperature. The parameters to use are the still heater power and the setting of the flow restriction valve above the counterflow heat exchanger (CVCF). After each change allow the refrigerator to come to equilibrium (approx 30 minutes). The refrigerator may also be sensitive to the amount of helium-3 condensed in the system, and this may be varied by adding or removing gas in the circulation stream.

6. LOADING THE TARGET INTO THE CRYOSTAT

This section describes the procedures to be followed to load that target into the IBC and returning the refrigerator to its operating temperature.

6.1 Preparing the refrigerator

The target is loaded into the refrigerator at about 1.2 K and this may cause a bump in the turbo pump inlet pressure. Hence before loading, the turbo speed should be lowered to about half value, and the still power should be reduced to zero.

6.2 Energize the transfer and holding magnets.

6.3 Procedure for target installation

6.3.1 Move the in-beam cryostat to the insertion position.
6.3.2 Connect the transfer cryostat to the in-beam cryostat.
6.3.3 Evacuate the connection space between the two cryostats to less than 10^{-4} Torr
6.3.4 Open the two transfer vacuum valves
6.3.5 Open the in-beam cryostat shutter
6.3.6 Insert the target holder and screw it to the refrigerator
6.3.7 Remove the target transfer mechanism
6.3.8 Close the two transfer vacuum valves
6.3.9 Close the in-beam cryostat shutter
6.3.10 Disconnect the transfer cryostat from the in-beam cryostat

6.4 Cooling the refrigerator

6.4.1 As the turbo pump inlet pressure allows, bring the turbo back to full speed.
6.4.2 Raise the still power back to its nominal value.
6.4.3 Tune the refrigerator as in section 5.4.

7.REMOVING THE TARGET FROM THE IN-BEAM CRYOSTAT

This section describes the removal of the target from the IBC.

7.1Preparing the refrigerator

Before the target retraction device (assumed to be at about 1.2 K) can be attached to the target, the refrigerator must be prepared for the accompanying temperature rise. The turbo speed should be lowered to about half value, and the still power should be reduced to zero.

7.2Procedure for target removal

7.2.1Move the in-beam cryostat to the insertion position
7.2.2Connect the transfer cryostat to the in-beam cryostat
7.2.3Evacuate the connection space between the two cryostats to less than 10E-4 Torr
7.2.4Open the two transfer vacuum valves
7.2.5Open the in-beam cryostat shutter
7.2.6Insert the target holder and screw it to the target, loosening the target from the refrigerator
7.2.7Remove the target
7.2.8Close the two transfer vacuum valves
7.2.9Close the in-beam cryostat shutter
7.2.10Disconnect the transfer cryostat from the in-beam cryostat

8.WARMING THE IN-BEAM CRYOSTAT

This section describes the procedures to be followed to recover the operating gas mixture from the refrigerator, turn off the magnet, turn off the pumps, set the valves, and allow the IBC warm to room temperature.

8.1Ramp down and turn off the magnet power supply

8.2Recover the gas from the refrigerator

8.2.1Open CV18 and close V12
8.2.2Turn on the mixing chamber heater
8.2.3When the pressure in the He-3 Dump has risen to its designated storage value, close V20 and open V19
8.2.4When the mixing chamber temperature rises above 2 K, reduce the mixing chamber heater to maintain this temperature. When the pressure at PI1 drops to zero (all gas recovered), turn off the mixing chamber heater and turn off the still heater. Close CV18 and V19
8.2.5Close V16

8.3Close V1 and V23 and turn off TP1.

8.4Close V4 and V28 and turn off the rotary mechanical pump M151b

8.5Turn off the automatic LN2 filler to the cryostat LN2 reservoir (CVLN2)

8.6Turn off the automatic LN2 filler to the gas cleaner (CV23)

8.7Leave cryostat to warm naturally (about 2 days)

9.AFTER THE CRYOSTAT HAS WARMED

This section describes the procedures required for the final shut-down of the IBC.

9.1After the cryostat has warmed to above 273 K, close all remaining valves and turn off all remaining pumps.

SAFETY CONSIDERATIONS IN OPERATING THE BNL IN-BEAM CRYOSTAT

(May 23, 2003)

Following are a number of unusual circumstances which may arise in the operation of the IBC, and the expected response of the IBC to these circumstances, in the absence of operator iintervention.

1.ELECTRICAL POWER FAILURE

In the event of a power failure, the pumps will cease operating and certain electrically driven values may change state. The circulation pumps (typically TP1 and M151b) switch off. CV9 and CV18 immediately open and the turbo exhaust sees the return line pressure of up to about 500 Torr. This pressure will rapidly decline as the gas goes back to the dump via CV18, but there is likely to be a rapid turbo blade deceleration.

The helium liquid in the refrigerator will evaporate slowly and pass back to the storage tanks via the normally open valves CV9 and CV18. If power is restored before all the liquid has evaporated, then the circulation pumps can be restarted and the refrigerator brought back into operation. If for some reason V1 has been closed so the gas can't get back to the storage tanks, then the volume of the flexible pump line (6" ID x approx 13 ' long) will allow the pressure to rise to about 1.3 bar, whereupon some gas may vent through S13.

The 1K and 2K pot pumps likewise stop, and the fill valves for these pots close slowly, with an approximate five minute time constant. The liquid trapped in these two pots evaporates slowly and escapes through relief valves to the experimental hall.

There is no pump on the insulation vacuum space of the cryostat and the vacuum will be maintained by cryopumping to the helium reservoir so long as there is liquid helium in the reservoir. Depending on the depth of helium at the time of the power failure, this should be several hours. The hold time of the IBC reservoir is expected to be in excess of 24 hours.

The polarization holding magnet power supply should be on UPS and see no loss of field until the magnet warms due to the loss of the 2K pump.

The thermally actuated valves (CV1K, CV2K, CVBY, and CVCF) are operated by heaters (the valves are opened by the differential expansion of two metals) that are located outside the cryostat. Power on causes the valves to open and when thej power fails they will close slowly as the actuators cool.

2.LOSS OF SERVICE AIR PRESSURE

The IBC does not use service air.

3.LOSS OF COOLING WATER

The bearings of the turbopump are water cooled. In the event of the loss of cooling water, the bearing temperature will rise and the turbopump power supply will shut off the pump. This will leave only the mechanical pump circulating the refrigerator helium and one will see (a possibly considerable) target temperature rise.

4.LIQUID NITROGEN FAILURE

Liquid nitrogen is held in a small reservoir in the IBC to cool the outermost shield, and in another small reservoir in the pumping package to cool a flow through gas cleaner. These reservoirs are automatically refilled from a large transport dewar. If this dewar goes empty, then the small reservoirs will not refill, causing excessive heating in the IBC (due to the outer shield failure) and possible plugging of the refrigerator (if the flow through gas cleaner warms). The large transport dewar should have a pressure sensor on it to signal if it goes empty (if its head pressure falls to zero).

5.ATMOSPHERIC PRESSURE ON THE IBC

There are two areas of concern about the external atmospheric pressure on the IBC, the thin walled snout and the mylar beam exit window. The snout is an aluminum tube 80 mm OD, 1 mm wall, and about 1 m long. Its calculated collapsing pressure is 41 PSID. The mylar beam exit window glued into the end of this tube is torospherical in shape and between 4 and 5 thousandths of an inch thick. Several windows were manufactured, one ("good looking") one glued into the tube and another (not quite so "good looking") one glued into a test jig where it was subjected to a pressure test and burst at 100 PSID.

If the thin walled snout collapses under the atmospheric load, it will come to rest against the LN2 cooled shield and the effect of this will be to warm this shield and increase the heat load on the refrigerator. Since there are still two more shields around the target, it is not expected that the target will warm to the subliming temperature.

6.VACUUM LEAKS

A slow air leak from the outside will simply condense on the helium reservoir and will not be noticed until this reservoir is deliberately warmed at the end of the run.

A slow helium leak inside the cryostat will degrade insulation vacuum and cause an increasing heat leak to the cryogen reservoirs and to the refrigerator. Eventually the target will begin to sublime, but even if it vaporizes entirely, it will only raise the pressure inside the cryostat to about 80 Torr.

7.CATASTROPHIC LOSS OF INSULATING VACUUM

If this occurs due to a sudden dump of helium into the vacuum space, then the target will sublime rapidly, mix with helium at a very low density, and be blown out through the downstream window and/or through the IBC vent in the top plate. There should be no explosion hazard.

If the occurrence is due to a catastrophic air leak, then a similar scenario would ensue except the approximately 20 atmospheric liters of hydrogen from the target would be mixed with air, and the potential for a small combustion event would exist for a few seconds.

In either case, the pressure in the helium reservoir would rise to maybe 5 atm (all the liquid converted to a supercritical gas at about the same temperature). The stress in the stainless steel walls of the helium reservoir would rise to about 10,000 psi and the gas would vent through a 2” dia tube (about 16” long) to the experimental hall in one or two seconds. The total amount of gas involved would be about 40,000 atm-liters. The vent is about 8 feet above the floor and as long as it is directed up, there should be no personnel hazard.

The thermally actuated valves (CV1K, CV2K, CVBY, and CVCF) have actuators (heaters) outside the cryostat and are not much affected by the state of the cryostat vacuum.

Brookhaven National Laboratory

Hazard Identification Tool

Operation Title: LEGS New Inbeam Cryostat
Point Of Contact: Michael Lowry
Hazard Rating: 2 (explanation of rating)

Required Documentation:

Because of the hazards identified, this operation has the potential of being an operation with a **medium initial risk**. Please ensure that you adequately address the magnitude of the hazard (i.e., quantity, duration, frequency, physical state) in your analysis.

The following questions were answered YES and contributed to a hazard rating of 2:

6a. Is there any electrical equipment used in the operation with voltages less then 50V and power less than 1000W OR voltage greater than 50V and current less than 5mA AND stored energy less than 10 J.?
6b. Is there any electrical equipment used in the operation with voltage less than 50V and power greater than 1000W OR voltage from 50V to 250V and current greater than 5mA OR voltage greater than 250V and current less than 500 mA AND stored energy less than 10J?
6c. Is there any electrical equipment used in the operation involving voltages greater 250V and current greater than 500A OR stored energy greater than 10J?
8. Do you work with any of the following non-ionizing radiation (NIR) sources: permanently installed Radio Frequency Micro Wave (RFMW) gear capable of radiating over 1 W into an open area at frequencies between 3 kHz and 300 GHz or of emitting over 100 W if the output is normally completely enclosed by coaxial cables, waveguides, or dummy or real loads; satellite and permanently installed communications transmitters (not receivers); portable walkie-talkie communications sets capable of radiating over 7 W at frequencies between 100 kHz and 450 MHz, and over 7 (450/f) W at frequencies between 450 MHz and 1.0 GHz (f in MHz); induction heaters. (Microwave ovens used as a household appliance, cellular phones, video display terminals, and radar speed Guns are exempt.); or any equipment that would expose personnel to high levels of sub-radiofrequency electric or magnetic fields including static electric and magnetic fields.
10c. Is there a pressure system present in the operation involving cryogenic system or Dewar installation equipped with a pressure relief device set above 15 psig, regardless of the estimated amount of potential stored energy?
14b. Will operation require work outside normal working hours?

Notes:

- (6) All energized electrical equipment must be included in the equipment inventory for your group. Contact the Electrical Safety Officer for more information.
- (6) A list of nationally recognized testing laboratories and recognized manufacturers is available from the ESO
- (8) NIR sources must be listed on the BNL NIR inventory and may require measurements to be

taken. If your equipment is not part of this inventory, please contact your FSS representative for further guidance. Note in your analysis that sources are included in the inventory.

- (10c, 10d) The SHSD Safety Engineering Group, prior to use, must review this type of pressure system. Contact your FSS representative for additional guidance. Note operating parameter in your analysis.

BNL Requirements:

ESH Standard 2.3.2 RF and Microwave
Magnetic Fields, Static subject area
ESH Standard 5.1.0 Nonflammable Cryogenic Liquids
ESH Standard 1.4.0 Compressed Gas Safety
ESH Standard 1.4.1 Pressurized Systems for Experimental Use
ESH Standard 1.4.2 Glass and Plastic Window Design for Pressure Vessels
ESH Standard 5.2.0 Flammable Cryogenic Liquids

BNL Lessons Learned:

BNL Lessons Learned: Electrical/NEC
BNL Lessons Learned: Personal Injury/Exposure, Hazardous Materials (General)
BNL Lessons Learned: Personal Injury/Exposure, Other
BNL Lessons Learned: Human Factors
BNL Lessons Learned: Human Resources
BNL Lessons Learned: Personal Injury/Exposure, Ambient Temperature Extremes
BNL Lessons Learned: Pressurized Systems

References:

Department Of Energy
OSHA Code of Federal Regulations
National Fire Protection Agency
American National Standards Institute
Institute of Electrical and Electronics Engineers, Inc.
American conference of Governmental Industrial Hygienists
29 CFR 1910 Subpart S - Electrical Safety (29 CFR 1910.301-308)
29 CFR 1926 Subpart K - Electrical (29 CFR 1926.400-499)
ANSI National Electrical Safety Code (ANSI-C2)
NFPA National Electrical Safety Code (NFPA-70 and 70E)
ESH Standard 1.5.2 Design Criteria for Electrical Equipment
Electrical Safety Implementation Guide
ESH Standard 1.5.1 Lockout/Tagout Requirements
ESH Standard 1.5.0 Electrical Safety
29 CFR 1920.97 Non-ionizing Radiation
ACGIH Threshold Limit Values and Biological Exposure Indices
DOE Order 5480.4 Environmental Protection, Safety, and Health Protection Standards
AR 14-1 Pressure Systems Including Compressed Gas Systems
Matheson Gas Data Book

IEEE Std C95.1 Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields

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Privacy and Security Notice

LEGS Oxygen Deficiency Hazard Protection System (June 23/99)

Location and potential ODH sources

A system of cryogenic devices is in the process of being installed at the Laser-Electron-Gamma-Source (LEGS) in the NSLS, Building 725, for use with a new frozen spin deuterium-hydride (HD) target. These are listed below, with the indicated liquid cryogen capacity. Also listed are the rooms in which these devices will be used, the two possibilities being Rm. 168 (the LEGS *Target room*) or Rm. 169 (the LEGS *Cryolab*) – see attached drawing.

	LHe capacity	LN_2 capacity	Location
(1) *Storage* dewar (Janis-III),	50 liters,	25 liters,	Rm. 168,169;
(2) *Transfer* Cryostat (Orsay),	2 liters,	5 liters,	Rm. 168,169;
(3) *In-beam* Cryostat (Orsay),	10 liters,	100 liters,	Rm. 168;
(4) *Production* Dewar (Janis-II),	30 liters,	20 liters,	Rm. 168,169;
(5) *Helium liquifier* (CTI-1410),	575 liters/day,	10 liters,	Rm. 169;
(6) *Dilution Fridge* (Oxford-1000),	80 liters,	50 liters,	Rm. 169;
(7) *HD-still* purifier (BNL),	0 liters,	0 liters,	Rm. 168,169;
(8) *Beth* magnet (out for bids),	50 liters,	0 liters,	Rm. 168.

Commercial liquid helium dewars (250 liters or 500 liters) will be used to fill the various reservoirs in these devices, and a 500 liter receiver dewar will be used to collect liquid from the helium liquifier.

There are two additional sources of Helium gas associated with the planned installation of the Helium liquifier. The Helium capacities and locations are as follows:

	He capacity	Location
(9) *Helium gas recovery bag*	500 cu ft (gas),	Rm. 168;
(10) *Helium compressors and tank*	42 cu ft (gas) @ 220 psi	MER#7.

The volume of the rooms in which these devices will be used is,

(A) LEGS *Target room*, Rm. 168 of Bldg. 725: 27000 cu. ft.;
(This does not include the LEGS *counting* rooms or *Control* room – see drawing).

(B) LEGS *Cryolab*, Rm. 169 of Bldg. 725: 6600 cu. ft;

(C) Mechanical Equipment Room #7 of Bldg. 725: 7100 cu. ft.

Largest potential Oxygen Deficiency Hazards

The greatest potential Oxygen Deficiency Hazard (ODH) is associated with the evaporation of a large quantity of liquid Helium. (Liquid nitrogen evolves gas at a comparatively slow rate even from a poorly insulated container.) The integrity of the commercial dewars used for transporting and storing liquid Helium are certified by their manufactures. The largest potential ODH would be caused by the quench of a superconducting magnet. Such a quench in either the *Storage* dewar or the *Beth* magnet dewar (1 or 8 in the above list) could potentially boil 50 liters of LHe in Rm. 168, releasing 1350 cu. ft. of He gas. A quench of the *Dilution Fridge* magnet could potentially boil 80 liters of LHe in Rm. 169, releasing 2160 cu. ft. of He gas. These gases would be released over the course of several minutes.

The LEGS *Target Room* (Rm. 168) has a staggered ceiling with a 20 ft. height over the main experimental area and 15 ft. in the area adjacent to the *Counting* rooms. A 2′ x 4′ automatic louvered damper is located in the side wall joining the 15′ and 20′ ceilings at a height of about 18′. The 1350 cu. ft. of He gas released from the boiling of 50 liters of LHe in Rm. 168 would immediately rise to the 20 ft. ceiling of the *Target room* and be exchanged with outside air through the existing louvered damper. There is a flow of at least 400 cu. ft./min. (cfm) through this damper when it is set at minimum opening (and 4000 cfm at maximum). No ODH is created in this situation.

The LEGS *Cryolab* (Rm. 169) has a 16 ft. ceiling, and a minimum air flow of 230 cfm from the NSLS air conditioning system. The 2160 cu. ft. of He gas released from the boiling of 80 liters of LHe in this room would displace approximately the upper 1/3 of the air. This could pose an ODH to someone who was on the equipment mezzanine of that room.

The LEGS *Counting rooms* are supplied with a minimum of 400 cfm of air, and the ***Control room*** with 300 cfm of air, both from the LEGS air conditioning system. These rooms are not in the path of Helium flow. When the door between the *Counting rooms* and the *Cryolab* is open the greater air supply to the *Counting rooms* ensures a net flow into the *Cryolab*. No ODH is associated with this room.

Mechanical Equipment Room number 7 (MER#7) in building 725 will house two gas compressors and an expansion tank associated with the planned helium liquifier system (in addition to existing equipment). This room has 7100 cu ft of air volume. The existing air system supplies up to 1380 cfm and exhausts up to 1580 cfm, with 200 cfm taken from the NSLS floor. (The room is designed to have a slight negative pressure.) When the *existing* ODH sensor in this room detects a low oxygen level it opens dampers and switches the exhaust and supply fans to high speed (to the above ratings). This exchanges the air in the room in about 5 minutes. The components of the LEGS liquifier system that are planned to be installed in MER#7 consist of two compressors (for the clean gas) with 1 psi in and 220 psi out, and an overflow tank to take up the gas from the compressors when the system is shut off. The tank holds up to 42 cu ft at 220 psi. In a worst case scenario, if the tank was completely full and somehow ruptured, the Helium would expand to 660 cu ft. That is less than 10% of the room volume and could be exhausted in about 25 seconds by the existing systems. This does not alter the ODH level for this room.

ODH protection

One new ODH sensor will be installed in the *Cryolab* near the ceiling above the Mezzanine on the South-West wall of Rm. 169. This device will be connected to NSLS Emergency Power and its calibration will be checked every 6 months.

No ODH sensor is needed in the *Target room* (Rm. 168), because of its large volume, and the existing ODH sensor in MER#7 is sufficient for the protection of that room.

A *Panel Ventura fan, Industrial Air* model 033, with a flow capacity of 8300 CFM, will be mounted near the ceiling in the wall panel between Rm. 169 and Rm. 168. This will exhaust gas from the *Cryolab* into the *Target room* (above the Counting Room Addition) when the *Cryolab* ODH sensor is activated. A 2nd identical 8300 CFM fan unit will be mounted on the roof behind the 2′ x 4′ damper. The damper will open and this 2nd fan will also be powered on whenever the *Cryolab* ODH sensor is activated.

Upon activation of the 8300 CFM fans make-up air will be provided,
(a) from the NSLS Experimental floor (bldg. 725) via 48″ x 30″ louvers which will be installed above the door to Rm. 169;
(b) from the NSLS Experimental floor (bldg. 725) via an existing 12″ x 36″ opening in Rm. 168 at the level of the monorail crane above the point where the beam-line enters the *Target room* (see drawing);
(c) from the LEGS air supply through a 2′ x 2′ cable trench from the floor of the *Target room* and through open floor panels that are used to route cables to electronics racks. The air flow will be through the grating on the top of the *Counting Room Addition,*

The Ventura fan units will have a manual control, as well as an automatic setting under the control of the ODH sensor. A super-conducting magnet quench is detectable before significant amounts of Helium begin to evolve. Upon detecting a quench, the standard procedure will be to immediately switch the fans on and evacuate both the *Target room* (168) and the *Cryolab* (169) for at least 5 minutes, even if the ODH sensor has not yet registered an oxygen depleted atmosphere.

While the *Cryolab* ODH sensor will be connected to NSLS Emergency Power, the two Ventura fan units will not (due to insufficient capacity in Bldg. 725). In the case of a power interruption, LEGS or NSLS-Target-Watch staff will begin procedures to place magnets in their *safe states*. However, if either a quench is detected or the *Cryolab* ODH sensor alarms, all personnel must evacuate rooms 168 and 169 and may not return until power has been restored to the Ventura fan units, which will run until the ODH has been eliminated (as indicated by the audio ODH horn alarm).

All LEGS personnel, including staff, students and collaborators, will be trained in the above ODH procedures. This will be incorporated into the basic *Beam Line Safety Awareness Training* for the X5 (LEGS) beam line.

ODH from failure of commercial dewars

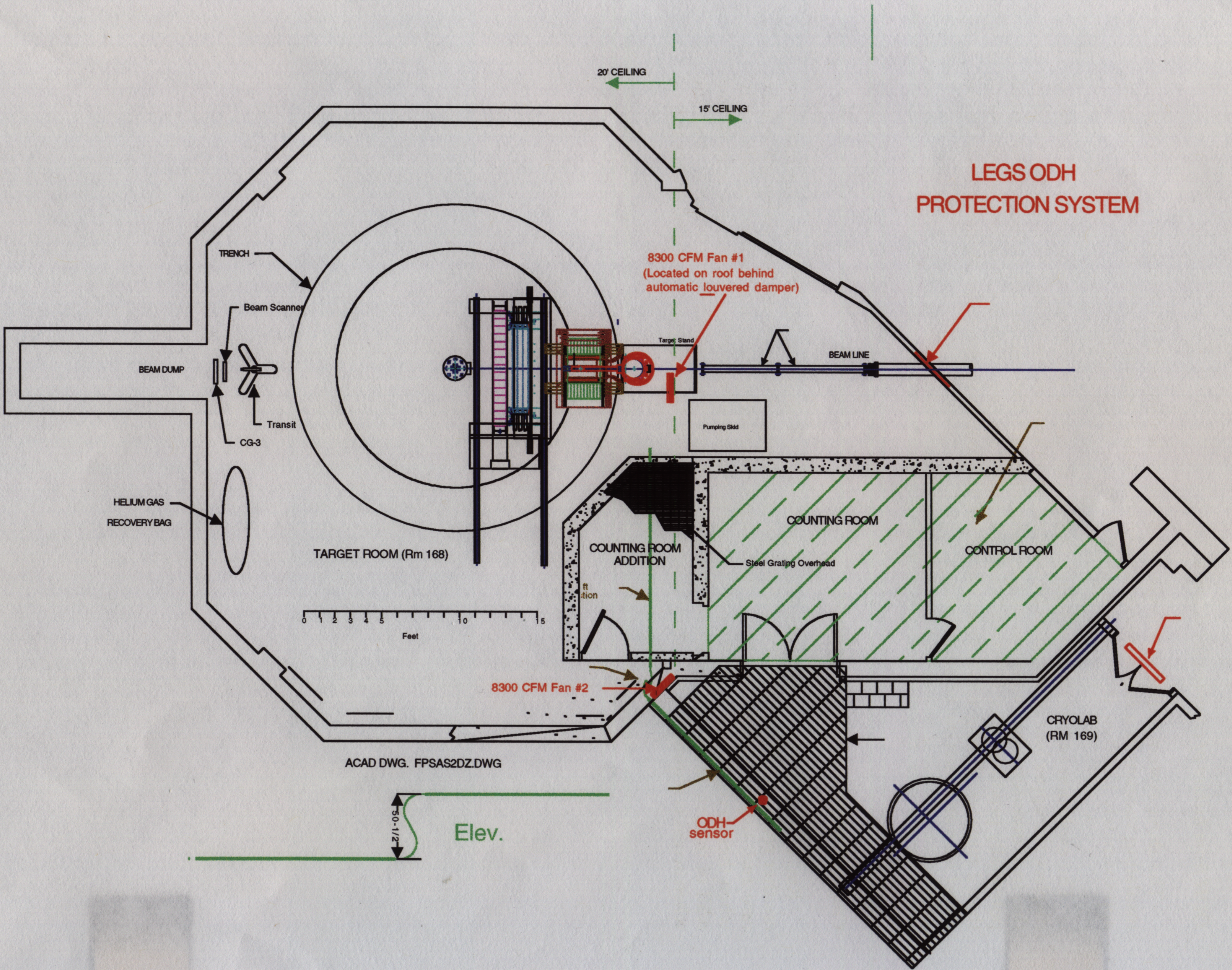
The above system will also provide a method of dealing with the extreme case of a loss of insulating vacuum in a full 500 liter commercial liquid helium dewar. This would result in approximately 13500 cu. ft. of helium gas evolving in about 5 minutes.

The evolution of 500 liters of liquid Helium to gas in the *Target room* could potentially displace the upper half of the room air volume. Switching on the 8300 CFM fan unit will clear this in 2 minutes. The evolution of 500 liters of liquid Helium to gas in the *Cryolab* could potentially produce twice the room's volume in helium gas. However, this would take more than 2 minutes, during which time the 8300 CFM fans will sweep the helium first into the *Target room* and then out of the building.

Confined Space Hazards and controls

Rm. 169 contains two floor pits, one round 5′ ID x 8′ deep for the *Dilution refrigerator,* and another rectangular 2′4″ x 3′4″ x 3′ deep for the *Storage dewar.* Access into either pit will be rare and, to protect the integrity of their super-conducting magnets, will be possible only when their cryogenic devices are not operating and have been rolled to the side against one wall of the pit. A fan positioned on the floor will direct airflow down into the 8′ deep pit when access is required. The 3′ deep is waist height and does not pose a significant hazard.

LEGS ODH PROTECTION SYSTEM



BNL In-Beam Cryostat Device State Table (Dilution Refrigerator Option) Revised May 1/03									
Device Name	Device Status								
	Prior to Step 1	Prior to Step 2	Prior to Step 3	Prior to Step 4	Prior to Step 5	Prior to Step 6	Prior to Step 7	Prior to Step 8	Prior to Step 9
TP1	off	off	on	on	on	on	on	on	off
TP1a	off	off	off	off	off	off	off	off	off
M151a	off	off	off	off	off	off	off	off	off
M151b	off	off	on	on	on	on	on	on	off
VP1	off	on	on	on	on	on	on	on	off
VP2	off	on	on	on	on	on	on	on	off
Shutter	closed	closed	closed	closed	closed	closed	closed	closed	closed
BR3	closed	closed	open	open	open	open	open	open	open
BR4	closed	closed	open	open	open	open	open	open	open
BR5	closed	closed	open	open	open	open	open	open	open
BR6	closed	closed	open	open	open	open	open	open	open
BR7	closed	closed	open	open	open	open	open	open	open
V1	closed	closed	open	open	open	open	open	open	closed
V2	closed	closed	closed	closed	closed	closed	closed	closed	closed
V3	closed	closed	closed	closed	closed	closed	closed	closed	closed
V4	closed	closed	open	open	open	open	open	open	closed
CV5	open	open	open	open	open	open	open	open	open
V6	open	open	open	open	open	open	open	open	open
V7	open	open	open	open	open	open	open	open	open
V8	open	open	open	open	open	open	open	open	open
CV9	open	open	closed	closed	closed	closed	closed	closed	open
V10	open	open	open	open	open	open	open	open	open
V11	closed	closed	closed	closed	closed	closed	closed	closed	closed
V12	closed	open	open	open	open	open	open	open	closed
V13	closed	closed	closed	closed	closed	closed	closed	closed	closed
V14	closed	closed	closed	closed	closed	closed	closed	closed	closed
V15	closed	closed	closed	closed	closed	closed	closed	closed	closed
V16	closed	closed	open	open	open	open	open	open	closed
V17	closed	closed	closed	closed	closed	closed	closed	closed	closed
CV18	closed	auto	auto	auto	auto	auto	auto	auto	closed
V19	closed	open	open	open	open	closed	closed	closed	closed
V20	closed	closed	closed	closed	closed	open	open	open	closed
V21	closed	closed	closed	closed	closed	closed	closed	closed	closed
CV23	closed	auto	auto	auto	auto	auto	auto	auto	closed
V23	closed	open	open	open	open	open	open	open	closed
V23a	closed	closed	closed	closed	closed	closed	closed	closed	closed
V24	closed	closed	closed	closed	closed	closed	closed	closed	closed
V25	closed	closed	closed	closed	closed	closed	closed	closed	closed
VP25	closed	open	closed	closed	closed	closed	closed	closed	closed
V26	closed	closed	closed	closed	closed	closed	closed	closed	closed
VP26	closed	closed	closed	closed	closed	closed	closed	closed	closed
V27	closed	closed	closed	closed	closed	closed	closed	closed	closed
V28	closed	closed	open	open	open	open	open	open	closed
V29	closed	closed	closed	closed	closed	closed	closed	closed	closed
CV1K	closed	open	open	auto	auto	auto	auto	auto	closed
CV2K	closed	open	open	auto	auto	auto	auto	auto	closed
CVBY	closed	open	open	auto	auto	auto	auto	auto	auto
CVCF	closed	open	open	open	open	open	auto	auto	auto
CVLN2	closed	closed	auto	auto	auto	auto	auto	auto	closed
V1K	closed	closed	open/ .5	open	open	open	open	open	closed
V2K	closed	closed	open/ .5	open	open	open	open	open	closed
VFILL	closed	open	closed	closed	closed	closed	closed	closed	closed
VP25	closed	open	closed	closed	closed	closed	closed	closed	closed
VP26	closed	closed	closed	closed	closed	closed	closed	closed	closed
VT2	closed	closed	closed	closed	closed	closed	closed	closed	closed
VTC1	closed	open	open	closed	closed	closed	closed	closed	closed
VTC2	closed	open	open	closed	closed	closed	closed	closed	closed
V1KT	closed	closed	open	open	open	open	open	open	closed

Building 911B
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-4250
Fax 631 344-5954
lessard@bnl.gov

BROOKHAVEN
NATIONAL LABORATORY

Date: *August 27, 2003*

To: *T. Sheridan, Deputy Director for Operations*

From: *E. Lessard, Chair, BNL Environment, Safety and Health Committee* ETL

Subject: *LESHC 03-05, Conditional Recommendation for Approval of Operation for the Physics Department LEGS In-Beam Cryostat Replacement*

The Cryogenic Safety Subcommittee of the BNL ES&H Committee has reviewed the proposed installation of a Physics Department Laser Electron Gamma Source (LEGS) In-Beam Cryostat Replacement in our meeting of August 4, 2003. The LEGS In-Beam Cryostat is a commercially available unit that will replace an existing unit located in the National Synchrotron Light Source LEGS Target Room (Room 168 of Building 725). The Minutes of LESHC Meeting 03-05 are attached to this memo for your information. The Minutes contain two Committee Motions. Motion 1 documents several conditions that must be completed prior to the start of the In-Beam Cryostat commissioning process. Motion 2 presents additional Committee requirements that must be completed prior to the start of In-Beam Cryostat operations.

The Committee recommends granting the Physics Department approval for operation of the LEGS In-Beam Cryostat Replacement, subject to the completion of the conditions associated with the Committee Commissioning and Operation Motions.

CC w/ attachment (via Email):

LESHC Members
Meeting Attendees
S. Aronson
M. Beckman
L. Hinchliffe (BAO)
T. Kirk
L. Marascia
T. Monahan
S. Musolino
T. Sheridan
J. Tarpinian
M. Zarcone

Analysis of the LEGS Oxygen Deficiency Hazard Protection System

A.M. Sandorfi
(March 15, 2004)

Executive Summary

This document presents an analysis of the Oxygen Deficiency Hazards (ODH) associated with the LEGS facility at the National Synchrotron Light Source, Bldg. 725. This is an update to the June 23, 1999 ODH document and incorporates the analysis requirements as defined in the SBMS subject area: *Oxygen Deficiency Hazards (ODH), System Classification and Controls*.

Sources of potential hazards are discussed and *Fatality Rates* are calculated for three rooms in Bldg. 725, the LEGS *Cryolab* (1-169), the LEGS *target room* (1-168) and the NSLS *mechanical equipment room number 7* (MER#7). The regions in these rooms with the highest possible hazard are considered and the calculations for the five worst cases are described in detail. With the adoption of one administrative control, namely to restrict the volume of liquid helium (LHe) in a cryogenic supply dewar to less than 250 liters when in the LEGS target room (1-168), rooms 1-169 and 1-168 classify as ODH-0, and MER#7 retains its classification as ODH-0. The results are summarized as follows:

Location	Net Fatality Rate (hr^{-1})	Classification
Cryolab / 1-169	9.1×10^{-9}	**ODH-0**
Target room / 1-168	6.9×10^{-9} *	**ODH-0**
MER #7	0	**ODH-0**

* LHe in supply dewars limited to less than 250 liters.

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Location and potential ODH sources

A system of cryogenic devices is in the process of being installed at the Laser-Electron-Gamma-Source (LEGS) in the NSLS, Building 725, for use with a new frozen spin deuterium-hydride (HD) target. These are listed below, with the indicated liquid Helium (LHe) and liquid Nitrogen (LN_2) cryogen capacities. Also listed are the rooms in which these devices will be used, the two possibilities being Rm. 1-168 (the LEGS *Target room*) or Rm. 1-169 (the LEGS *Cryolab*) – see attached drawing.

			LHe capacity	LN_2 capacity	Location
(1)	*Storage* dewar/SD	(Janis-III),	50 liters,	25 liters,	Rm. 168,169;
(2a)	*Transfer* Cryostat/TC	(Orsay),	1 liters,	5 liters,	Rm. 168,169;
(2b)	*Transfer* Cryostat/TC	(Jülich),	1 liters,	5 liters,	Rm. 168,169;
(3a)	*In-beam* Cryostat/IBC	(Orsay),	9 liters,	0 liters,	Rm. 168;
(3b)	*In-beam* Cryostat/IBC	(Quantum),	45 liters,	5 liters,	Rm. 168;
(4)	*Production* Dewar/PD	(Janis-II),	20 liters,	20 liters,	Rm. 168,169;
(5)	*Dilution Fridge*/DF	(Oxford-1000),	96 liters,	50 liters,	Rm. 169;
(6)	*Beth* magnet		10 liters,	0 liters,	Rm. 168.

Commercial liquid helium dewars supplied by BOC Gas (250 liters or 500 liters) are used to fill the various reservoirs in these devices:

(7)	*BOC* supply dewars	500 liters	0 liters	Rm. 168,169

A commercial 500 liter receiver dewar is used to collect liquid from a helium liquifier in room 169; a 50 liter LN_2 trap is also used with the liquifier system:

(8)	*Helium liquifier* (CTI-1410),	500 liters,	50 liters,	Rm. 169;

Three additional sources of Helium gas are associated with the Helium liquifier. The Helium capacities and locations are as follows:

		He gas capacity	Location
(9)	*He gas recovery bag*	500 cu ft (gas),	Rm. 168;
(10)	*He Recovery compressor*	334 cu ft (gas) @ 2200 psi (exterior tube trailer)	Rm. 168;
(11)	*He compressors and tank*	42 cu ft (gas) @ 220 psi	MER#7.

The volume of the rooms in which these devices are used is,

(A) LEGS *Target room*, Rm. 168 of Bldg. 725: 27000 cu. ft.;
(This does not include the LEGS *counting* rooms or *Control* room – see drawing).

(B) LEGS *Cryolab*, Rm. 169 of Bldg. 725: 6600 cu. ft;

(C) Mechanical Equipment Room #7 of Bldg. 725: 7100 cu. ft.

Room layouts and standard ventilation

The LEGS *Target Room* (Rm. 168) has a staggered ceiling with a 20 ft. height over the main experimental area and 15 ft. in the area adjacent to the *Counting rooms*. Over the *Counting rooms* there is an A/C-equipment mezzanine. A 2′ x 4′ automatic louvered damper is located in the side wall joining the 15′ and 20′ ceilings at a height of about 18′. The LEGS A/C system generates a flow of at least 400 cu. ft./min. (cfm) through this damper when it is set at minimum opening (and 4000 cfm at maximum).

The LEGS *Cryolab* (Rm. 169) has a 16 ft. ceiling, a volume of 6600 cu ft and a minimum air flow of 230 cfm from the NSLS air conditioning system. A mezzanine is located against the south-west wall and houses a helium liquifier engine and vacuum pumps.

The LEGS *Counting room* and adjacent **Counting room addition** are supplied with a minimum of 400 cfm of air, and the ***Control room*** with 300 cfm of air, both from the LEGS air conditioning system. Cryostats are not used in these rooms and the rooms are not in the path of Helium flow. (When the door between the *Counting rooms* and the *Cryolab* is open the greater air supply to the *Counting rooms* ensures a net flow into the *Cryolab*.)

Mechanical Equipment Room number 7 (MER#7) in building 725 houses two gas compressors and an expansion tank associated with the LEGS helium liquifier system (in addition to other NSLS equipment). This room has 7100 cu ft of air volume. The existing air system supplies up to 1380 cfm and exhausts up to 1580 cfm, with 200 cfm taken from the NSLS floor. (The room is designed to have a slight negative pressure.)

O_2 Sensors and Emergency Ventilation

An O_2 sensor is installed in the *Cryolab* near the ceiling above the Mezzanine on the South-West wall of Rm. 169. This device is connected to NSLS Emergency Power and its calibration is checked every 6 months by NSLS Operations staff.

An O_2 sensor is in service in MER#7. It is also connected to NSLS Emergency Power and its calibration is checked every 6 months.

A *Panel Ventura exhaust fan* (EF-1), *Industrial Air* model 033, with a rated flow capacity of 8300 cfm, is mounted near the ceiling in the wall panel between Rm. 169 and Rm. 168. This exhausts gas from the *Cryolab* into the *Target room* (above the Counting Room Addition) and is activated whenever the *Cryolab* O_2 sensor registers an O_2 level less than 19.5%. A 2nd identical 8300 cfm *Ventura* exhaust fan (EF-2) unit is mounted on the roof behind the 2′ x 4′ damper. Whenever the *Cryolab* O_2 sensor registers a low level this damper opens and the 2nd *Ventura* fan is also powered on. We have the option of installing an interlock on the door accessing the A/C-equipment mezzanine in 1-168 which can power the EF-2 unit (but not EF-1) if the door is open or the interlock is not satisfied, indicating potential occupancy of the A/C mezzanine. (This option is discussed in *case 3* below.)

The air flow produced by these exhaust fans has been directly measured by Plant Engineering with an accuracy of about 5% using digital Anemometers:

- with both EF-1 and EF-2 powered, the fresh air flow into room 1-169 is 8050 cfm;
- with EF-2 only powered on, the flow out of the roof vent above Rm. 168 was measured at 4110 cfm, (consistent with the limitations of the roof damper).

Upon activation of the *Ventura* fans make-up air is provided:
(a) from the NSLS Experimental floor (bldg. 725) via 60″ x 30″ louvers which are installed above the door to Rm. 169;
(b) from the NSLS Experimental floor (bldg. 725) via a 12″ x 36″ opening in Rm. 168 at the level of the monorail crane above the point where the beam-line enters the *Target room* (see drawing);
(c) from the LEGS air supply through a 2′ x 2′ cable trench from the floor of the *Target room* and through open floor panels that are used to route cables to electronics racks. The air flow will be through the grating on the top of the Counting Room Addition.

The Ventura fan units have a manual control, as well as an automatic setting under the control of the O_2 sensor. A super-conducting magnet quench is detectable before significant amounts of Helium begin to evolve. Upon detecting a quench, the standard procedure is to immediately switch the fans on and evacuate both the *Target room* (168) and the *Cryolab* (169) for at least 5 minutes, even if the O_2 sensor has not yet registered an oxygen depleted atmosphere. (All LEGS personnel, including staff, students and collaborators, are trained in these procedures. This has been incorporated into the basic *Beam Line Safety Awareness Training* for the X5 - LEGS beam line.)

While the *Cryolab* O_2 sensor is connected to NSLS Emergency Power, the two Ventura fan units are not (due to insufficient capacity in Bldg. 725). In the case of a power interruption, LEGS or NSLS-Target-Watch staff will begin procedures to place magnets in their *safe states*. However, if either a quench is detected or the *Cryolab* O_2 sensor alarms to indicate an O_2 concentration below 19.5%, all personnel are instructed to evacuate rooms 168 and 169 and may not return until power has been restored to the Ventura fan units, which will run until any ODH has been eliminated (as indicated by the audio O_2 horn alarm).

When the O_2 sensor in *MER#7* detects an oxygen level below 19.5% dampers opens and the exhaust and supply fans are switched to high speed (to 1580 cfm and 1380 cfm, respectively). This exchanges the air in the room in about 5 minutes.

Oxygen Deficiency Hazards

The greatest potential Oxygen Deficiency Hazard (ODH) is associated with the evaporation of a large quantity of liquid Helium due to the loss of insulating vacuum in a cryostat. (Liquid nitrogen evolves gas at a comparatively slow rate even from a poorly insulated container.) When the temperature of a LHe vessel is suddenly raised above 4K, a He vapor layer forms between the LHe and the walls of its container. The rate of He gas evolution depends on the heat transfer across this layer between the surface of the LHe and the vessel, and this depends on the construction of the cryostat. The heat transfer resulting from the sudden venting of dewars was studied at CERN to evaluate the safety systems of the SPS accelerator. Three different classes of dewars were identified:

(a) multi-wrap (~200) super-insulated commercial dewars with gas-cooled shields;
(b) dewars LN_2 shields and some modest (~10 wraps) super-insulation;
(c) dewars with LN_2 shields, but no super-insulation.

All dewars at BNL are equipped with relief valves which in the event of an accident vent He gas through lines > 20 mm ∅. In the CERN study, the relief valves were removed and typically 100 liquid liters were allowed to directly vent out the top of dewars through 30 mm – 50 mm ∅ tubes as air rushed into the insulating vacuum. Their measured heat transfers are listed in Table 1.

Table 1. Heat transfers across the surface of LHe following the venting of three different types of cryostats. Measurements taken from W. Lehmann and G. Zahn, "*Safety aspects for LHe cryostats and LHe transport containers*", Proc. 7th Int. Cryogenic Engineering Conf., London (1978) 569.

Cryostat shielding	*max* $\dot{Q}$ (W/cm^2)
(a) commercial transport: multi-wrap (~200) super-insulation with gas-cooled shields	2.0
(b) LN_2 shield; some super-insulation (~10 wraps)	0.6
(c) LN_2 shields; no super-insulation	3.8

In these tests, the heat transfer rose quickly (in ~ 7 to 12 sec) to a maximum and then, for configurations (a) and (c), dropped significantly due to the decrease in temperature from evaporation and the increasing insulation of the growing solid-air layer. For dewar configuration (b), the heat transfer decreased only slightly after reaching the peak value in Table 1. Here we tabulate the measured *peak* heat-transfer values. In the following calculations we include an additional safety margin by assuming the above peak heat transfer values persist throughout the boil-down. Dewar configuration (b) clearly has a significantly lower heat transfer. Some of our LN_2-shielded dewars are similar to the class-(b) cryostat used in the CERN study, but not identical. In those cases we take the conservative approach of designating them class-(c).

Using the above heat transfer values, the boil-down time and the He gas evolution rate can be calculated. We first outline the steps in the calculation and then illustrate the results with examples.

Calculation of the He gas evolution rate

In the event of a sudden loss of the insulating vacuum, solid air will freeze on the outside of the LHe volume at 61 K. The LHe boils as energy is transferred across the $\Delta T = 61\text{-}4\ K = 57\ K$ interface. The heat capacity of LHe at 4K is,

$$C_V = 2.6\ \mathrm{J/g°K}\ ,$$

and the density of LHe at 4K is,

$$\rho = 124{,}000\ \mathrm{g/m^3}\ .$$

A temperature difference of ΔT across the walls of the LHe vessel of volume V generates a potential energy of $Q = C_V\ \Delta T\ \rho\ V$, so that when the LHe level drops by dz, the LHe volume drops by dV and the energy released is,

$$dQ = C_V\ \Delta T\ \rho\ dV \quad \text{(Joules).} \tag{1}$$

From Table 1, the heat transfer resulting from the venting of the insulation vacuum is,

$$\dot{Q} \quad \text{in W/cm}^2 \text{ or } 10^4\ \text{W/m}^2\ , \tag{2}$$

and the boil-down time associated with this change is,

$$\mathrm{d}t_{BD} = \mathrm{d}Q/(\dot{Q}\mathrm{A}) \quad \text{(sec)}, \tag{3}$$

where A is the surface area of the $\Delta T = 57$ K interface. The instantaneous liquid-loss rate is then $\mathrm{d}V/\mathrm{d}t_{BD}$ (in m^3/s). One liter of LHe expands to 27 cu ft of gas at STP, so that the instantaneous rate of He gas evolution (R) is,

$$\textit{He evolution rate}, R \text{ (in } \textit{cfm}) = (27000 \times 60) \times \frac{dV\,(m^3)}{dt_{BD}\,(s)}. \tag{4}$$

As the LHe level drops, the remaining volume of liquid and the corresponding area in contact with the warm dewar walls also drop, and so R drops. The calculations start with the maximum capacity of LHe and follow the changes until all the LHe has been boiled.

Evaluation of O_2 concentration and the associated Fatality Factor

We consider the release of He gas at a rate R (cfm) in a room of volume V_{rm} (cu ft) with fresh air intake S (cfm) and exhaust E (cfm) = $R+S$. The O_2 concentration as a function of time, $C(t)$, follows the differential equation,

$$V_{rm}\frac{dC(t)}{dt} = C_f \cdot S - (R+S)\cdot C(t)\,, \tag{5}$$

where C_f is the O_2 concentration in fresh air, $C_f = 0.21$. For a time interval sufficiently short that S and R can be considered constant over the interval, the solution to this equation is,

$$C(t) = C_f \cdot \frac{S}{R+S} + \left(C_o - C_f \cdot \frac{S}{R+S}\right)\cdot e^{-(R+S)t\,/\,V_{rm}}\,, \qquad \text{for } t \le t_{BD}\,, \tag{6}$$

where C_0 is the O_2 concentration at the beginning of the time interval. The release continues until the boil-down of the cryostat is complete, at $t = t_{BD}$, and the O_2 concentration reaches the value C_{BD} . At times longer than t_{BD} the concentration follows the same differential equation in (5), but with $R = 0$, $E = S$ and boundary conditions $C(t_{BD}) = C_{BD}$ and $C(\infty) = C_f = 0.21$. The solution with these boundary conditions is,

$$C(t) = C_f + (C_{BD} - C_f)\cdot e^{-S(t-t_{BD})\,/\,V_{rm}}, \quad \text{for } t > t_{BD}\,. \tag{7}$$

The partial pressure of O_2 with this concentration, in mm Hg, is $P_{O2} = 760 \bullet C(t)$ and the associated *Fatality Factor* (F) is taken from the minimum in $C(t)$,

$$F = 10^{\,(67-760\cdot C^{min})\,/\,10}\,, \tag{8}$$

and for $760 \bullet C^{min} < 67$ mm Hg, F is set to 1.0 ; by convention, if $C^{min} > 0.18$ then F is set to 0.0 .

With these relations, the time profile of the O_2 concentration and its minimum value can be calculated, and from this the Fatality Factor can be deduced.

Table 2. Equipment failure rates from the loss of insulating vacuum in LEGS cryostats, and from the rupture of the He Recovery Compressor or its piping.

Cryostat/Equipment	Equipment Failure Rate, **P** (hr^{-1})
SD, IBCs, PD, DF, Beth	1×10^{-6}
TCs	1×10^{-2}
Commercial supply dewars	1×10^{-6}
Recovery Compressor rupture	3×10^{-7}
He gas piping	1×10^{-9}

Equipment failure rates and the resulting Fatality Rate

The estimate for the failure rate of dewars is taken from the FermiLab report by B. Soyars, "*FermiLab Equipment Failure Rate Estimates, Appendix Table B-I*", dated Jan. 26, 2000. This report lists a failure rate of $P=1 \times 10^{-6}$ per hour for a leak or rupture in a helium dewar. We use this value for all LEGS cryostats except the two Transfer cryostats. The integrity of the insulating vacuum for the latter depends on several welded bellows that are compressed and extended when these devices are used. Experience has shown that the TC failure rate due to leaks in a bellows is on the order of 10^{-2} per hour. These rates are summarized in Table 2. The 4^{th} row lists the Fermi Lab estimate for the rupture of the He recovery Compressor located in the LEGS target room, 1-168. The last row gives the failure rate for the associated piping.

The net fatality rate is the product of the fatality factor and the equipment failure rate,

$$\textbf{Fatality Rate} = PF \,. \tag{9}$$

We illustrate these calculations using cases which result in the largest releases of helium.

Case 1: Fatality Rate Calculation for the loss of insulating vacuum in a Commercial 500 l dewar in the LEGS Cryolab (Rm. 1-169)

The LEGS *Cryolab* (Rm. 169) has a 16 ft. ceiling, a volume of 6600 cu ft and a minimum air flow of 230 cfm from the NSLS air conditioning system. The largest possible Fatality Rate will occur on the equipment mezzanine located against the south-west wall of the room. Thus, for the purposes of these calculations we take the relevant volume as the upper half of the room volume, or $V_{rm} = 3300$ *cu ft*. The liquid helium vessel in a 500 liter commercial transport dewar is approximately a 39" ∅ sphere with volume V = 0.50 m^3 and surface area A = 3.05 m^2. This is a class-(a) cryostat, for which we take the heat transfer of eqn. (2) as 2.0×10^4 W/m^2 from Table 1. The rate of He gas evolution (R) following the sudden loss of insulating vacuum at time $t = 0$ in such a commercial dewar located in Rm. 169 is shown in figure 1 by the blue curve. The resulting $C(O_2)$ oxygen concentration follows the red curve. In these calculations the liquid level is reduced in 0.01 m decrements which results in a series of time intervals determined by eqn. (3). The main features of the calculation are as follows:

- Using the standard room ventilation into this space of $S=230$ *cfm*, the concentration of O_2 follows eqn. (6) and drops to 19.5% in about 0.05 min or 3 sec.
- The Ventura fans then turn on, giving an exhaust $E = 8050$ *cfm* which draws in fresh air at the rate $S = E - R$ *cfm*. The O_2 concentration again follows eqn. (6), reaching a minimum of 0.119 after 0.95 min. as the fresh air draw finally catches up to the initial He release. The concentration then rises as the LHe volume and the area in contact with the hot dewar walls continues to decrease.

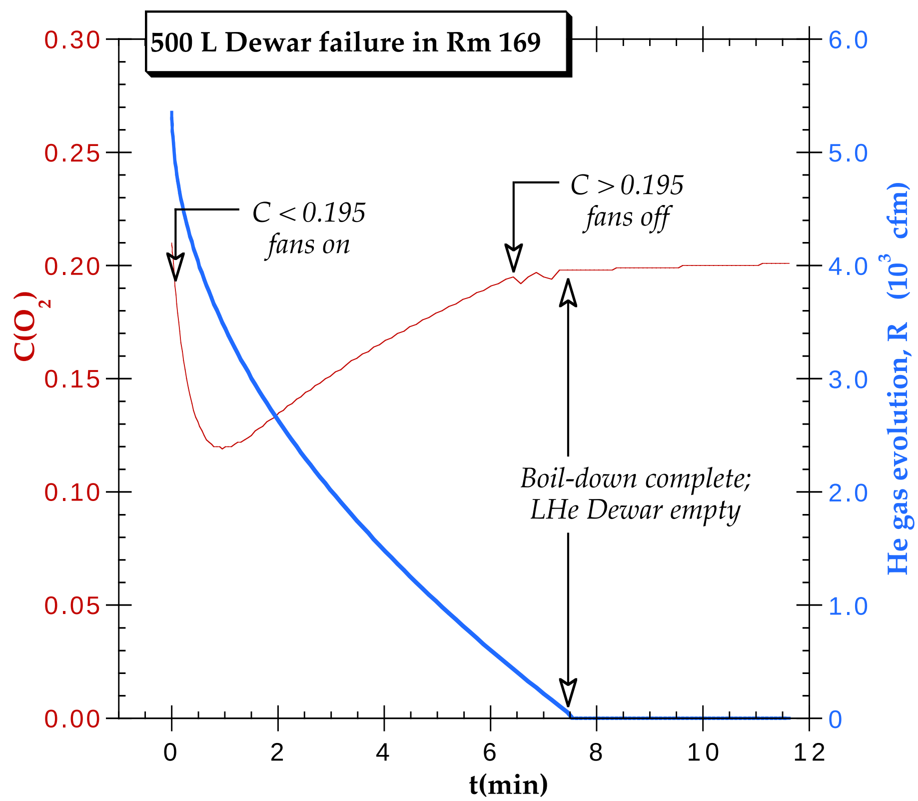


Figure 1. The time evolution of the O_2 concentration on the mezzanine of room 1-169 following a sudden loss of insulating vacuum in a commercial 500 liter dewar.

- After 6.43 min the concentration rises above 19.5% and the Ventura fans initially shut off. The O_2 concentration continues to follow eqn. (6), with the $S = 230\ cfm$ air supplied by the NSLS AC system. However, since the He gas evolution rate (R) is still significantly larger than this NSLS fresh air supply, the concentration momentarily drops and the Ventura fans go through two more cycles before the dewar runs completely dry.
- After $t_{BD} = 7.45\ min$, or 447 sec, the dewar is empty. This agrees favorably with the boil-down times observed by Lehmann and Zahn of about 1 sec per liquid liter for commercial supply dewars. The O_2 concentration at boil-down is $C_{BD} = 0.198$. The concentration then rises according to eqn. (7) with fresh air supplied by the NSLS AC system at $S = 230\ cfm$.

In calculating the Fatality rate, we take the minimum in the oxygen concentration of 0.119.

- This results in a partial pressure of O_2, P_{O2}=760•C_{min} = 90.4 mm Hg.
- From eqn. (8), the resulting Fatality Factor is $F = 4.5 \times 10^{-3}$.
- Using the failure rate of P=1×10^{-6} hr^{-1} from Table 2 for a leak in a commercial helium dewar, the net *Fatality Rate* from eqn. (9) is $\boldsymbol{PF = 4.5 \times 10^{-9}}$ **per hour**.

Case 2: Fatality Rate Calculation for the loss of insulating vacuum in the LEGS Dilution Refrigerator in the LEGS Cryolab (Rm. 1-169)

We next consider the sudden loss of insulating vacuum in the LEGS Dilution Refrigerator located in Rm. 169 and its impact for personnel on the equipment mezzanine. For this calculation we again consider only the upper half of the room 1-169 volume V_{rm} = 3300 cu ft.

The DF LHe bath volume is V = 0.096 m^3 and the surface area surrounded by insulating vacuum is A = 2.260 m^2. This is a class-(c) cryostat , for which we take the heat transfer of eqn. (2) as 3.8 × 10^4 W/m^2 from Table 1. The rate of He gas evolution (*R*) following the sudden loss of the DF insulating vacuum at time *t = 0* is shown as the blue curve in figure 2. The resulting C(O_2) oxygen concentration follows the red curve of figure 2. The main features of the calculation are as follows:

- Using the standard room ventilation into this space of *S=230 cfm*, the concentration of O_2 follows eqn. (6) and drops to 19.5% in about 0.04 min.
- At this point the Ventura fans turn on providing an exhaust *E = 8050 cfm*, which draws in fresh air at the rate *S = E - R cfm*. The O_2 concentration then follows eqn. (6) and reaches a minimum of 0.142 after 0.39 min. The concentration then rises as the LHe volume and the area in contact with the hot walls of the LHe bath decrease.
- After t_{BD} = *0.82 min* the DF is empty and the O_2 concentration is C_{BD} = *0.154*. The concentration then rises according to eqn. (7) as the Ventura fans continue to draw fresh air into the room at the rate *S = 8050 cfm*.
- After 1.41 min the concentration rises above 19.5% and the Ventura fans shut off. The O_2 concentration then continues to rise at a rate determined by eqn. (7), with C_{BD} replaced by *0.195* and t_{BD} replaced by *1.41 min* (the time-zero conditions for this final interval), due to the *S = 230 cfm* fresh air supplied by the NSLS AC system.

For the calculation of the Fatality rate, we take the minimum in the oxygen concentration of C_{min} = 0.142 .

- This results in a partial pressure of O_2 , P_{O2}=760•C_{min} = 107.9 mm Hg.

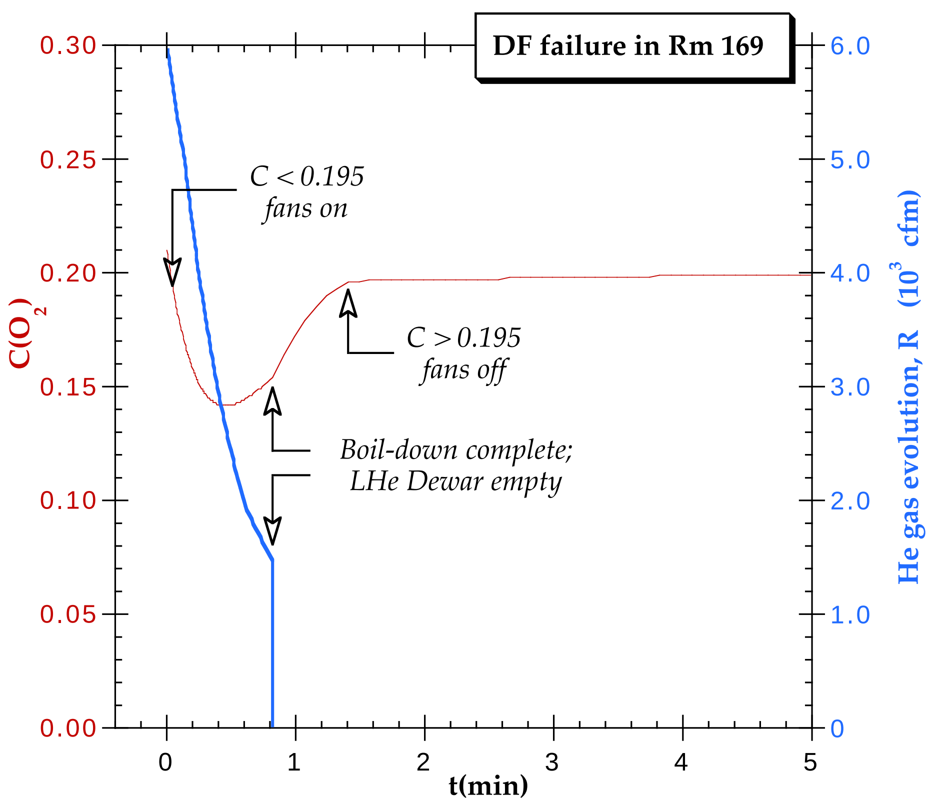


Figure 2. The time evolution of the O_2 concentration on the mezzanine of room 1-169 following a sudden loss of insulating vacuum in the LEGS Dilution Refrigerator.

- From eqn. (8), the resulting Fatality Factor is $F = 8.1 \times 10^{-5}$.
- Using the equipment failure rate of P=1×10^{-6} hr^{-1} from Table 2 for a leak in a helium dewar, the net *Fatality Rate* is ***PF* = 8.1×10^{-11} per hour**.

The above calculations have been repeated for each of the cryostats in use at LEGS. The results for the LEGS Cryolab (Rm 169) are summarized in Table 3 below. The net total fatality factor for the equipment mezzanine of room 1-169 (the *Cryolab*) is 9.1×10^{-9}. This is clearly dominated by the 500 L commercial supply dewars.

For personnel on the floor level area of the Cryolab, the relevant volume is the full room volume of V_{rm} = 6600 cu ft. Repeating the calculations for the failure of a 500 L commercial dewar then results in a minimum O_2 concentration of C^{min} = 0.133 which yields a fatality rate of 3.9×10^{-10} hr^{-1}, or an order of magnitude smaller than for the mezzanine area (rows 7 or 8 of Table 3). Similar reductions are encountered for the other failure cases of Table 3.

We recall the assumptions that make the above calculations quite conservative:

- The heat transfer rates in Table 1 are taken as the maximum values reported by Lehmann and Zahn and ignore the very significant reductions in heat transfer which they observed after the maximum is reached;
- Although the thermal shielding in several LEGS cryostats places them somewhere between classes (b) and (c) of Table 1, in such cases we assign them to the higher heat transfer class (c) category.

Table 3. LEGS cryostats that could be used simultaneously in room 1-169, together with their LHe capacity (V), the surface area (A) surrounded by insulating vacuum, the heat transfer rate from Table 1 following a loss of insulating vacuum, the calculated minimum in the O_2 concentration on the mezzanine in the upper half of 1-169 and the fatality factor (F) from eqn. (8). Using the equipment failure rates from Table 2 for each cryostat, the last column gives the net fatality rate **PF**.

Cryostat	*V* (m^3)	*A* (m^2)	$\dot{Q}$ (W/m^2)	$C(O_2)^{min}$	*fatality factor* **F**	*fatality rate* **PF** (hr^{-1})
(1) *SD*	0.050	0.777	3.8×10^4	0.178	1.5×10^{-7}	1.5×10^{-13}
(2a) *TC-Orsay*	0.001	0.142	3.8×10^4	0.208	0	0
(2b) *TC-Jülich*	0.001	0.142	3.8×10^4	0.208	0	0
(3a) *IBC-Orsay*	0.009	0.114	3.8×10^4	–	–	–
(3b) *IBC-Q*	0.045	0.570	3.8×10^4	–	–	–
(4) *PD*	0.020	0.412	3.8×10^4	0.194	0	0
(5) *DF*	0.098	1.782	3.8×10^4	0.142	8.1×10^{-5}	8.1×10^{-11}
(6) *ßeth magnet*	0.010	1.820	3.8×10^4	–	–	–
(7) *500 L BOC dewars*	0.500	3.040	2.0×10^4	0.119	4.5×10^{-3}	4.5×10^{-9}
(8) *Liquifier CTI receiver*	0.500	3.040	2.0×10^4	0.119	4.5×10^{-3}	4.5×10^{-9}
(9) *He gas recovery bag*	14.16	–	–	–	–	–
(10) *Recovery Compressor*	9.46	–	–	–	–	–
(10b) *Compressor piping*	9.46	–	–	–	–	–
Total:						**9.1×10^{-9}**

- We use the absolute minimum in the O_2 concentration to calculate the Fatality Factor, even though this minimum may only last a few seconds.

In conclusion, the Fatality Rate for room 1-169 is more than an order of magnitude less than 10^{-7} hr^{-1}, which determines its classification as **ODH class-0**.

Case 3: Fatality Rate Calculation for the Rm 1-168 A/C Mezzanine from a loss of insulating vacuum in Commercial dewars located on the floor of the LEGS target room (1-168)

We next consider the sudden loss of insulating vacuum in a commercial supply dewar located in the LEGS target room (1-168). Its impact will be greatest for personnel on the A/C equipment mezzanine. The A/C mezzanine is a *low-occupancy* region within the LEGS target room located above the counting and control rooms. The floor of this mezzanine is about 9′ above the target room floor. Two thirds of this area is located in the part of rm. 1-168 with a 15′ ceiling and so the mezzanine ceiling height in this region is about 6′. The rest of the mezzanine extends into the 20′ ceiling section of the building. (See attached layout.) Bounded on two sides by walls, this mezzanine has a volume of approximately 3040 cu ft, half of which is filled with equipment and air-conditioning ducts. Thus the air space in this mezzanine region is approximately V_{rm} = 1520 cu ft.

He gas rises at approximately 1 ft/s and so will quickly mix with air in the *upper half* of room 1-168. While there could be some small fraction of He gas at lower levels of the room due to turbulence, here we assume the worse case of all evolved gas limited to the upper half of the target room. The A/C mezzanine region is not in the direct path of any He gas that could evolve from a dewar or cryostat, and A/C ducts located around the perimeter of this area direct air flow away from the mezzanine. Nonetheless, in the following calculations we assume that air/gas in the mezzanine completely mixes with air/gas in the upper half of the target room. The full volume of room 1-168 is approximately 27000 cu ft, and so we take the rate of He gas evolving into the mezzanine region from the upper half of the target room as,

$$R_{mezz} = R \times (1520/13500) \tag{10a}$$

where R is the He evolution rate from eqn. (4). The LEGS A/C system generates a fresh air flow of 400 cfm which is dumped into the upper half of room 1-168, and we assume a similar fraction enters the mezzanine area,

$$S_{mezz} = S_{A/C} \times (1520/13500) = 45 \text{ cfm.} \tag{10b}$$

As mentioned in the introductory sections, we have the option of installing an interlock on the door accessing the A/C-equipment mezzanine in 1-168 which can power the EF-2 Ventura Fan if the access door is open or the interlock is not satisfied, indicating potential occupancy of the A/C mezzanine. The EF-2 fan exhausts gas through the damper located 18′ above the target room floor and draws air out of the upper half of the room at 4110 cfm. The exhaust from the mezzanine is then,

$$E_{mezz} = E_{EF\text{-}2} \times (1520/13500) = 463 \text{ cfm,} \tag{10c}$$

and the fresh air entering the mezzanine becomes $S_{mezz} = E_{mezz} - R_{mezz}$.

Using the relations of eqn. (10) we can assess the potential hazard for personnel on the A/C mezzanine in the event of the sudden loss of insulating vacuum of a commercial dewar located on the target room floor. Two sizes of commercial LHe dewars are in use at LEGS,

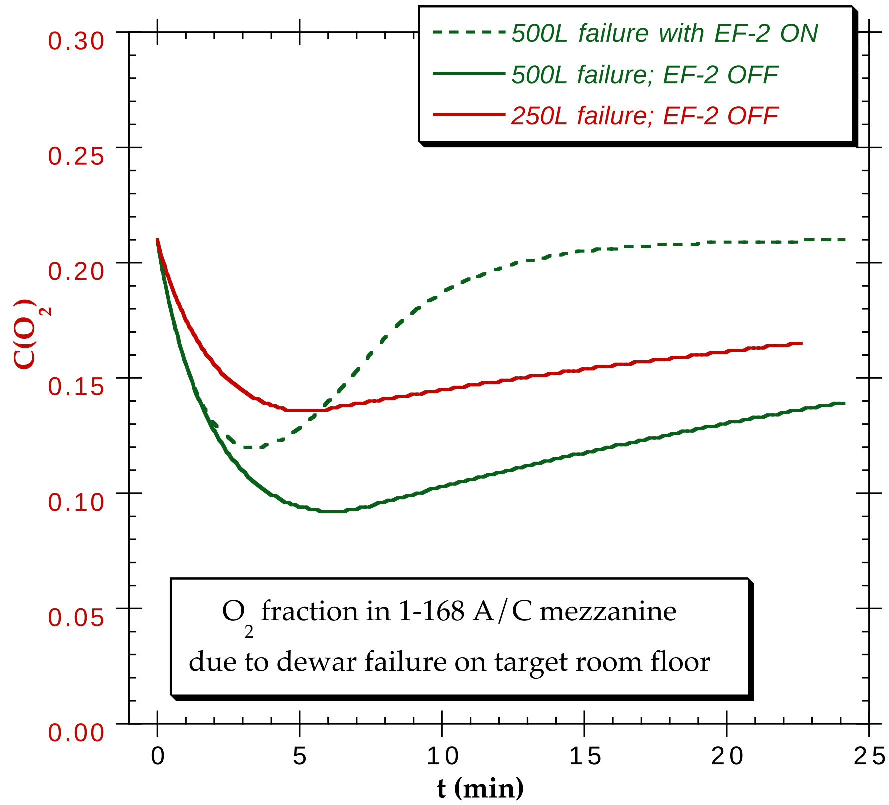


Figure 3. The time evolution of the O_2 concentration in the A/C mezzanine region of room 1-168 following the sudden loss of insulating vacuum in commercial dewars.

250 liters and 500 liters. The time evolution of the O_2 concentration in the mezzanine region following the loss of insulating vacuum in such dewars is shown in figure 3. In the case of the failure of a 250 L dewar (solid red curve), the concentration reaches a minimum of 0.136 . The associated Fatality Factor from eqn. (8) is 1.2×10^{-4} and combining this with dewar failure rate from Table 2 gives a net Fatality Rate of 1.2×10^{-10} hr^{-1}. This is consistent with an ODH class-0 designation for the LEGS target room. However, the minimum concentration reached when a commercial 500 L dewar fails (solid green curve) is 0.092 and the associated Fatality Factor is 0.5. Combining this with the anticipated dewar failure rate from Table 2 gives a net Fatality Rate of 0.5×10^{-6} hr^{-1}, which would require an ODH class-1 designation. This can be mitigated by interlocking the A/C mezzanine access door so that the EF-2 Ventura fan is powered on whenever there is potential occupancy (green dashed curve in figure 3). The minimum in $C(O_2)$ under these conditions is then 0.120 . The Fatality Factor for this concentration is 3.8×10^{-3} and combining this with the dewar failure rate from Table 2 gives a Fatality Rate of 3.8×10^{-9}, which is consistent with ODH class-0.

At present we have initiated administrative controls to limit the size of commercial dewars used in 1-168 to 250 L. Should the use of 500 L dewars become desirable, the above interlock for the A/C mezzanine door will be necessary to maintain an ODH class-0 designation for the LEGS target room.

These calculations have been repeated for each of the dewars and cryostats that could be used in room 1-168 and the results are summarized in Table 4. It is possible that as many as three 250 L supply dewars may be simultaneously located in the target room. So, for purposes of totaling the net Fatality Rate, entry (7) is repeated three times.

A 500 cu ft rubber bag is mounted on the back wall of the target room at a height of about 10 ft. and is used as a buffer volume for a He gas compressor. This bag is equipped with a 0.5 psi relief value. Nonetheless, we can imagine the scenario of a large tear somehow developing in the bag. Such a rupture could release the maximum contents of the bag in about a minute, so that R = 500 cfm for 1 min . This bag is located on the side of the target room opposite the A/C mezzanine and the emerging He would be fully mixed by the time it reached the mezzanine region. Thus R_{mezz} is given by eqn. (10a) above. Using the fresh air flow without the EF-2 Ventura fan from eqn. (10b), the O_2 concentration can be tracked with eqn. (6). The minimum is listed as the 9th entry in Table 4. While it is difficult to estimate the failure rate for the bag, since the minimum concentration is above 0.18, the Fatality factor is set to zero and there is no contribution to the net Fatality Rate.

Case 4: Fatality Rate Calculation for the Rm 1-168 A/C Mezzanine from the rupture of the He recovery compressor located on the floor of the LEGS target room (1-168)

A helium liquifier and gas recovery system is installed at LEGS. The liquifier engines are located on the mezzanine of the Cryolab, 1-169. Two compressors which feed gas to the liquifier engines are located in MER#7. A He gas Recovery compressor is mounted on the floor next to the west wall of the target room. This recovery compressor stores gas by pumping it into a 38-unit Tube-Trailer which is parked next to the North side of the building. The compressor is connected to the Tube-Trailer via a 500 ft stainless steel line (0.5″ O.D.; 0.4″ I.D.) which runs across the outside of the NSLS roof. The Tube-Trailer has a volume of 334 cu ft and can store gas at up to 2200 psi.

The greatest potential ODH hazard associated with the LEGS liquifier and recovery system is the possible rupture of the Recovery compressor which could lead to the venting of the contents of the storage Tube-Trailer into the target room. The failure rate for this compressor is listed in the last row of Table 2. The evolving gas would immediately rise into the upper half of the target room so that the greatest potential hazard occurs for personnel in the A/C equipment mezzanine of 1-169. We compute now the minimum O_2 concentration resulting from such a failure scenario.

We assume the rupture is sufficiently extensive to eliminate any impedance to the gas flow from the 0.5″ stainless line connected to the Tube-Trailer. The He mass flow emerging from this D = 0.4″ I.D. × L = 500 ft tube is determined by the following relations,

$$C_{Reynolds} = \frac{\Delta P \cdot \overline{P}}{L}\left(\frac{1}{RT}\frac{D^3}{\mu^2}\right) , \tag{11a}$$

$$M_{flow}^2 = \frac{40}{f'} \cdot C_{Reynolds} \cdot \left(\mu^2 D^2\right) , \tag{11b}$$

$$R = \frac{M_{flow}}{\rho_{He}} \cdot 60 \quad (cfm) . \tag{11c}$$

Here, ΔP is the pressure drop in lbs/ft^2 across the stainless line, which is just the pressure (P_{gas}) in the Tube-Trailer, and $\bar{P}$ is the average pressure in the line ($P_{gas}/2$). $R = 1545$ (*lb-ft/lb-°ℜ*) is the gas constant and T is the mean temperature of the gas, measured in ℜankine, which we take as 50+460 as a winter-summer average. The absolute viscosity of He gas, μ, is 1.32×10^{-5} *lb/ft-s* and the density of He gas is $\rho_{He} = 0.01114$ *lb/ft*^{3}. The friction factor, f', which appears in eqn. (11b) is a function of the $C_{Reynolds}$ parameter and we assume a relation corresponding to flow through smooth-walled pipes (W. Eshbach and M. Souders, *Handbook of Engineering Fundamentals*, Wiley, NY, 1975).

Assuming the maximum pressure in the Tube-Trailer at the start of the release, $P_{gas} = 2200 \times 12^2 = 316800$ *lb/ft*^{2}, $C_{Reynolds} = 2.9 \times 10^7$ (which corresponds to a Reynolds' index of 3×10^5) and this determines $f' = 0.020$. The gas release rate at the start of the discharge is then $R = 579$ cfm. The Recovery compressor is located on the side of the target room opposite the A/C mezzanine and the emerging He would be fully mixed by the time it reached the mezzanine region. Thus R_{mezz} is given by eqn. (10a) above. Using the fresh air flow without the EF-2 Ventura fan from eqn. (10b), the O_2 concentration is given by eqn. (6) for a time interval sufficiently short that R can be considered a constant. At the end of that interval, the *STP*-equivalent gas volume in the Tube-Trailer, V_{gas}, has been reduced to $(V_{gas} - R \bullet dt)/V_{gas}$ and, since the volume and temperature of the Tube-Trailer are constant, the pressure in the Tube-

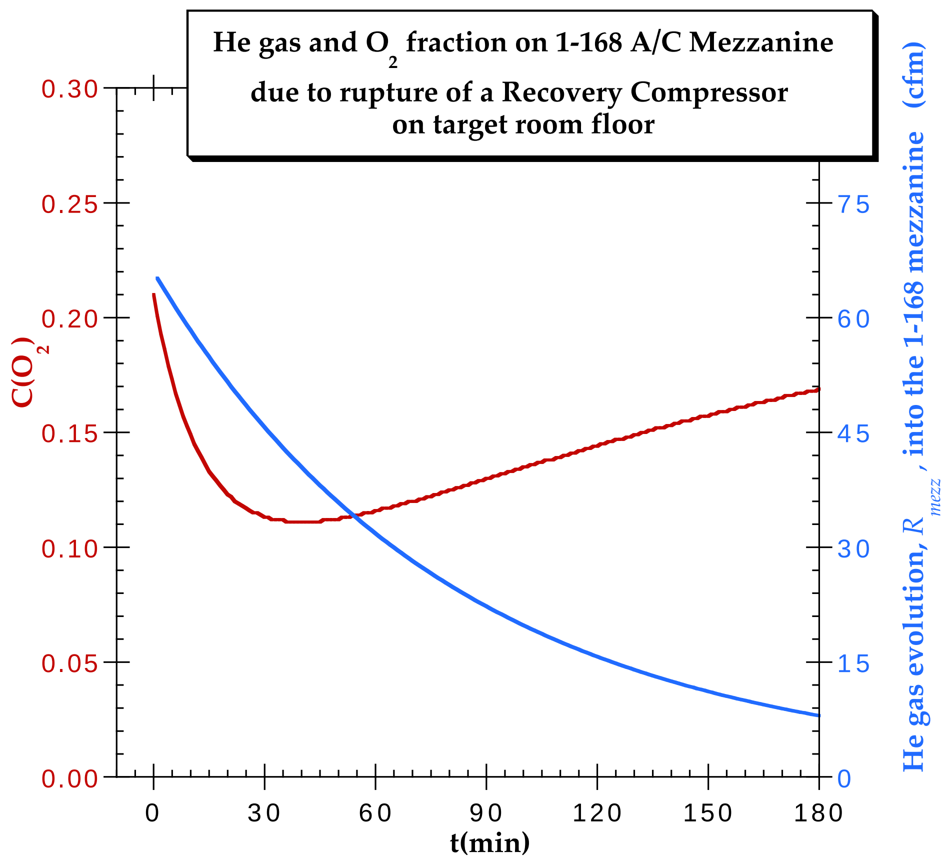


Figure 4. He gas released into the mezzanine region of 1-168 (in blue with scale on the right) together with the resulting O_2 concentration (in red with scale on the left) following the rupture of the LEGS Recovery compressor on the target room floor and the resulting discharge of the contents of the He gas Tube-Trailer into the target room.

Trailer (P_{gas}) is reduced by the same factor. The calculation proceeds in time increments dt until the Tube-Trailer is completely blown down to atmospheric pressure, which takes about 9.4 hr. The He gas released into the A/C mezzanine and the resulting O_2 concentration are plotted in figure 4.

A minimum O_2 concentration of 0.111 is reached after 36 min. From eqn. (8) the associated Fatality Factor is 1.8×10^{-2} and combining this with the expected failure rate of 3×10^{-7} hr^{-1} from Table 2 gives the expected Fatality Rate of 5.5×10^{-9} hr^{-1}. These values are listed below as the 10th entry in Table 4. (The *volume* in this entry is that of the Tube-Trailer.)

Finally we consider the rupture of the 0.5″ stainless steel line which passes through the A/C mezzanine. Without the EF-2 fan, this would lead to a very low O_2 concentration and a Fatality Factor of 1. However, the expected failure rate from Table 2 is 1×10^{-9} hr^{-1} so that the net Fatality Rate estimate is still only 1×10^{-9} hr^{-1}. This is included in the last row of Table 4.

The total Fatality Rate for the A/C mezzanine of room 1-168 is thus 6.9×10^{-9} hr^{-1} which determines its classification as **ODH class-0**. Because of the high ceiling in this room, and the fact that He gas rises at about 1 *ft/s*, Fatality Rates for the floor area of the target room can only be significantly smaller. Thus the entire LEGS target room is classified as **ODH class-0**.

Table 4. LEGS cryostats that could be used simultaneously in room 1-168, together with their LHe capacity (V), the surface area (A) surrounded by insulating vacuum, the heat transfer rate from Table 1 following a loss of insulating vacuum, the calculated minimum in the O_2 concentration in the A/C mezzanine region of 1-168 and the fatality factor (F) from eqn. (8). Three 250 L dewars could be used simultaneously and are hence entered three times. A He gas recover bag is included here as the ninth vessel. A He gas recovery compressor, connected to a Tube Trailer outside the building, is included as the tenth entry, along with its associated piping. The EF-2 Ventura fan is assumed to be *off* in these simulations. Using the equipment failure rates from Table 2 for each device, the last column gives the net fatality rate **PF**.

Cryostat	*V* (m^3)	*A* (m^2)	$\dot{Q}$ (W/m^2)	$C(O_2)^{min}$	*fatality factor* **F**	*fatality rate* **PF** (hr^{-1})
(1) *SD*	0.050	0.777	3.8×10^4	0.191	0	0
(2a) *TC-Orsay*	0.001	0.142	3.8×10^4	0.210	0	0
(2b) *TC-Jülich*	0.001	0.142	3.8×10^4	0.210	0	0
(3a) *IBC-Orsay*	0.009	0.114	3.8×10^4	0.205	0	0
(3b) *IBC-Q*	0.045	0.570	3.8×10^4	0.193	0	0
(4) *PD*	0.020	0.412	3.8×10^4	0.202	0	0
(5) *DF*	0.098	1.782	3.8×10^4	–	–	–
(6) *ßeth magnet*	0.010	1.820	3.8×10^4	0.204	0	0
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(8) *Liquifier CTI receiver*	0.500	3.040	2.0×10^4	–	–	–
(9) *He gas recovery bag*	14.16	–	–	0.202	0	0
(10) *Recovery Compressor*	9.46	–	–	0.111	1.8×10^{-2}	5.5×10^{-9}
(10b) *Compressor piping*	9.46	–	–	0.016	1	1.0×10^{-9}
Total:						6.9×10^{-9}

Case 5: Fatality Rate Calculation for MER#7 from the rupture of the He buffer tank

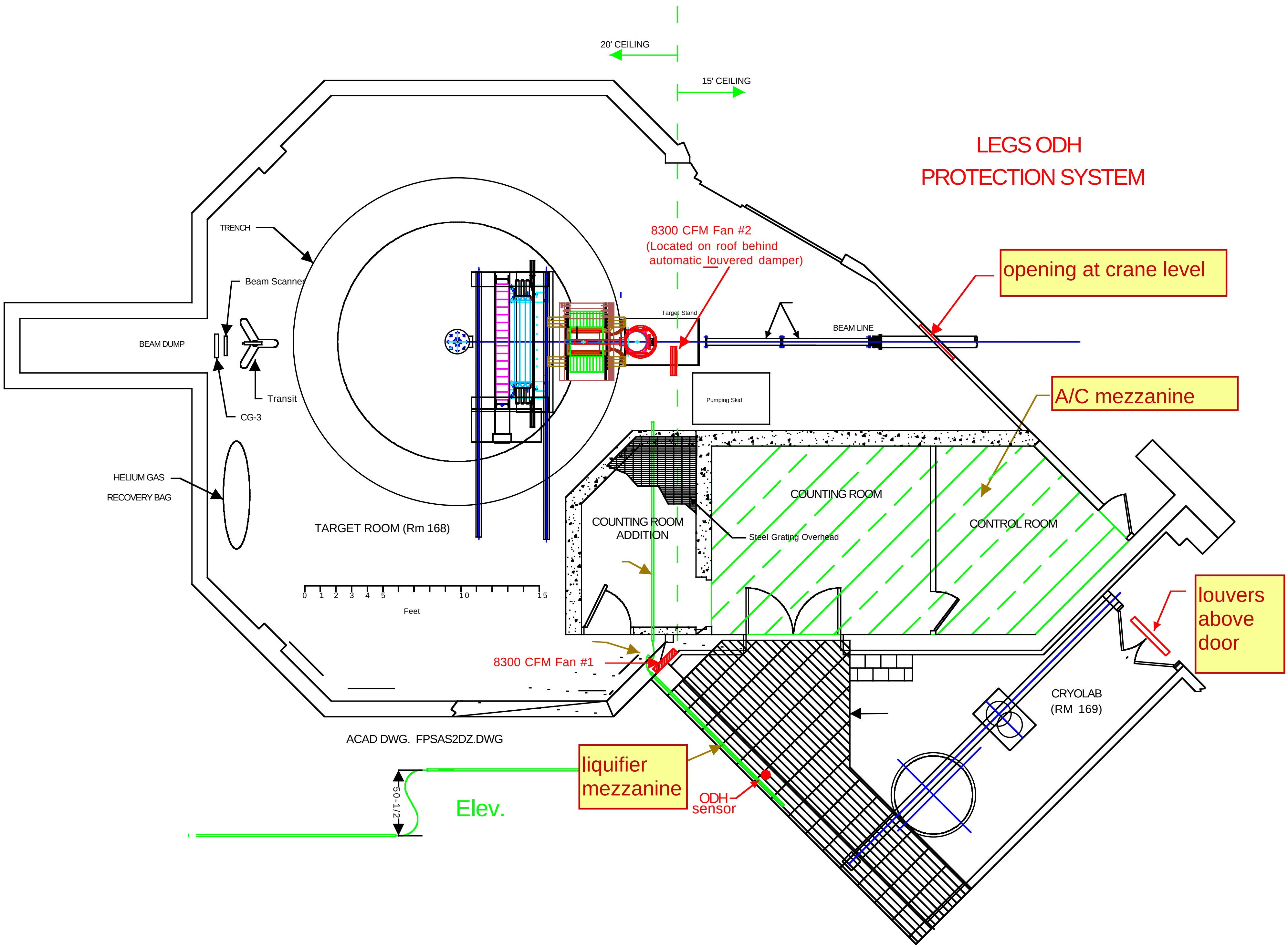
The components of the LEGS liquifier system that are installed in MER#7 consist of two compressors (for clean He gas) with 1 psi in and 220 psi out, and an overflow buffer tank to take up the gas from the compressors when the system is shut off. The tank holds up to 42 cu ft at 220 psi. In a worst case scenario, if the tank was completely full and ruptured, the Helium would expand to 660 cu ft. If we assume this happens over the course of one minute, then R = 660 cfm. Clean air is supplied to this room at the rate S = 1380 cfm and the O_2 concentration follows eqn (6). It reaches a minimum of 0.193 at the end of the 1 min release. The fatality Factor associated with this concentration is 0, and so this cannot alter the classification of this room as **ODH class-0**.

Confined Space Hazards and controls

Rm. 169 contains two floor pits, one round 5′ ID x 8′ deep for the *Dilution refrigerator*, and another rectangular 2′4″ x 3′4″ x 3′ deep for the *Storage dewar*. Access into either pit will be rare and, to protect the integrity of their super-conducting magnets, will be possible only when their cryogenic devices are not operating and have been rolled to the side against one wall of the pit. A fan positioned on the floor will direct airflow down into the 8′ deep pit when access is required. Such access is coordinated with NSLS Operation Coordinators. The 3′ deep is waist height and does not pose a significant hazard.

Transport of Commercial LHe Storage Dewars along the NSLS corridor to the LEGS area

LHe supply dewars for LEGS are delivered to the North-West rollup door of Bldg. 725 and brought down the outer access corridor of the X-ray ring experimental floor to the LEGS area. The failure rates listed in Table 2 are appropriate to equipment in use in a location for some extended number of hours, while the transport of dewars down the NSLS corridor last only minutes. The guidance given in the *SBMS* area under *ODH Calculation and Control Measures* (https://sbms.bnl.gov/standard/16/1601d011.htm) states, "**No assessment is required for areas temporarily used during transport of cryogenic dewars or compressed gases.**" Thus, no separate evaluation has been made for this case.



LEGS ODH
PROTECTION SYSTEM
20' CEILING
15' CEILING
8300 CFM Fan #2
(Located on roof behind
automatic louvered damper)
opening at crane level
TRENCH
Beam Scanner
Target Stand
BEAM LINE
BEAM DUMP
Transit
CG-3
Pumping Skid
A/C mezzanine
HELIUM GAS
RECOVERY BAG
TARGET ROOM (Rm 168)
COUNTING ROOM
COUNTING ROOM
ADDITION
Steel Grating Overhead
CONTROL ROOM
louvers
above
door
0 1 2 3 4 5 10 15
Feet
8300 CFM Fan #1
CRYOLAB
(RM 169)
ACAD DWG. FPSAS2DZ.DWG
liquifier
mezzanine
ODH
sensor
Elev.
50-1/2"

Lessard, Edward T

From: Sandorfi, Andrew
Sent: Wednesday, March 31, 2004 5:05 PM
To: Travis, Richard J; Lessard, Edward T
Subject: Re: LESHC 03-05, LEGS In-Beam Cryostat Replacement - Comments on the ODH Calculation

Follow Up Flag: Follow up
Flag Status: Flagged

AMS ODH
arification memo.pdf

Dear Rich and Ed,
Please find attached a memo addressing the three points you raised in your 3/29/04 Email.
I hope this clarifies all the ODH-related issues. Andy On 3/29/04 5:24 PM, "Travis,
Richard J" <travis@bnl.gov> wrote:
> Andy,
>
> On August 4, 2003 the Cryogenic Safety Subcommittee reviewed a
> proposed replacement for the Laser Electron Gamma Source (LEGS)
> located in the NSLS LEGS Target Room in Bldg 725. The LESHC 03-05
> meeting minutes and related material are located at:
>
> http://www.rhichome.bnl.gov/AGS/Accel/SND/LESHC/03-05%20minutes.pdf
>
> The Minutes have two motions containing 12 outstanding issues. Open
> item 1.2.1.2 states:
>
> 1.2.1.2. "Review the SBMS Subject Area "Oxygen Deficiency Hazards
> (ODH), System Classification and Controls"
> <https://sbms.bnl.gov/standard/16/1600t011.htm>, and perform the ODH
> calculations, both with and without the exhaust fans. Implement the
> appropriate control measures. Submit the calculations and the
> proposed control measures to the LESHC Cryogenic Subcommittee for
> review."
>
> In response to this open item, you submitted the calculation entitled,
> "Analysis of the LEGS Oxygen Deficiency Hazard Protection System",
> A.M. Sandorfi, dated 3/15/04.
>
> The Cryogenic Safety Subcommittee has reviewed this ODH analysis and
> offers the following comments:
>
> 1. Case B of the SBMS ODH exhibit, "Oxygen Concentration in Ventilated
> Spaces https://sbms.bnl.gov/standard/16/1602e011.htm provides a
> differential equation and solution for the oxygen mass balance for
> LEGS ventilation configuration. Although the LEGS equation 5 is the
> same as the SBMS differential equation, the LEGS solution (equation #
> 6) differs from the SBMS solution. Please clarify this apparent
> discrepancy.
>
> 2. Page 3 of the calculation credits semi annual calibration of the
> oxygen sensors. Please confirm that the entire loop is checked
> including the emergency exhaust fans (EF-!, 2).
>
> 3. An administrative limit to restrict the volume of LHe in a
> cryogenic supply dewar to less than 250 liters has been instituted
> for the LEGS Target Room (1-168). Please incorporate this limit into
> the "Beam Line Safety Awareness Training for the X5 - LEGS beam Line".

Laser-Electron-Gamma-Source, Physics Dept.

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 516 344-7951
Fax 516 344-2049
sandorfi@bnl.gov

BROOKHAVEN NATIONAL LABORATORY

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Memo

date: Mar. 30, 2004
to: Cryogenic Safety Subcommittee, LES&H committee
from: A.M. Sandorfi
subject: Clarifications to *Analysis of LEGS ODH Protection System* of March 15th, 2004

The following clarifications are offered in response to the questions posed in the March 29th, 2004 Email from R. Travis.

Point 1.) The derivation of eqns. (5) and (6) of the LEGS ODH report are quite straight forward. Consider the release of oxygen-free gas at a rate R (cfm) into a room of volume V (cf) with fresh air intake S (cfm) and exhaust E (cfm) = $R+S$ so that the room remains at atmospheric pressure. If the O_2 concentration at time t is C(t), then the volume of O_2 at time t is $V \cdot C(t)$. The volume of O_2 at $t + dt$ is increased by the fresh air intake, $C_f \cdot S \cdot dt$ where C_f = 0.21 is the concentration of O_2 in fresh air, and decreased by the exhaust, $C(t) \cdot E \cdot dt$, so that

$$V \cdot C(t) + V \cdot dC(t) = V \cdot C(t) + C_f S \cdot dt - C(t) \cdot E \cdot dt \quad .$$

The change in the O_2 concentration per unit time is then,

$$V \frac{dC(t)}{dt} = C_f \cdot S - E \cdot C(t) = C_f \cdot S - (R+S) \cdot C(t) \ , \qquad (i)$$

which is eqn. (5) of the LEGS ODH report. <u>Provided C(t) is the only time-dependent variable</u>, this class of differential equations has solutions of the form,

$$C(t) = \alpha + \beta e^{-\lambda t} \ . \qquad (ii)$$

Differentiating (ii) gives,

$$\begin{aligned} V \frac{dC(t)}{dt} &= -\lambda V \beta e^{-\lambda t} \\ &= V\lambda\alpha - V\lambda C(t) \end{aligned} \quad . \qquad (iii)$$

Comparing this with (i) immediately gives,

$$V\lambda = E \quad \text{or} \quad \lambda = (R+S)/V \ , \qquad (iv)$$

and,

$$V\lambda\alpha = C_f S \quad \text{or} \quad \alpha = \frac{C_f S}{E} = \frac{C_f S}{R+S} \ . \qquad (v)$$

If the O_2 concentration at time t=0 is denoted by C_o , then $C_o = \square + \square$ so that,

$$\square = C_o - \square \qquad \text{or} \qquad \square = C_o - \frac{C_f S}{R+S} \quad . \tag{vi}$$

Inserting (*iv*), (*v*) and (*vi*) into (*ii*) gives eqn. (6) of the LEGS ODH report:

$$C(t) = \frac{C_f S}{R+S} + \left(C_o - \frac{C_f S}{R+S} \right) e^{-(R+S)t/V} \quad . \tag{vii}$$

In the LEGS ODH analysis we have considered the release of helium gas from the boil down of liquid He dewars. In such a process the rate of evolution of He gas (R) is not a constant and furthermore, if an exhaust fan is powered on by an O_2 sensor at some point, then the fresh air intake (S) is also changing. Thus, in order to utilize this solution we must divide up the time duration of the release into many small intervals, each short enough so that R and S are approximately constant within each interval. In doing so, the clock of solution (*vii*) is reset for each interval, time t = 0 corresponds to the start of the interval and C_o is the concentration at that starting point.

In the limiting case where the source of the He release is <u>not</u> from a dewar boil-down but rather from some other source which is truly constant with time, then all intervals become equivalent and we could take time t = 0 as the start of the release and so set $C_o = C_f$, provided that the fresh air intake were also constant. Equation (*vii*) then trivially reduces to the expression in Case A of the SBMS ODH exhibit (*Oxygen Concentration in Ventilated Spaces*, https://sbms.bnl.gov/standard/16/1602e011.htm),

$$\begin{aligned} C(t) &= \frac{C_f S}{R+S} + \left(C_f - \frac{C_f S}{R+S} \right) e^{-(R+S)t/V} \\ &= \frac{C_f}{R+S} \left\{ S + \left(R + S - S \right) e^{-(R+S)t/V} \right\} \quad . \\ &= \frac{C_f}{R+S} \left\{ S + R e^{-(R+S)t/V} \right\} \end{aligned}$$

This is identical to the solution of SBMS case A with $Q_A = S$ and be easily recast into the form of the solution for SBMS case B where $Q_B = E = R + S$.

$$\begin{aligned} C(t) &= \frac{C_f}{R+S} \left\{ \quad S \quad + R e^{-(R+S)t/V} \right\} \\ &= \frac{C_f}{E} \left\{ E - R \ + R e^{-Et/V} \right\} \\ &= \frac{C_f}{E} \left\{ E - R \left(1 - e^{-Et/V} \right) \right\} \quad . \\ &= C_f \left[1 - \frac{R}{E} \left(1 - e^{-Et/V} \right) \right] \end{aligned}$$

However, due to the changing nature of R and S neither of these solutions are appropriate for this analysis.

Point 2.) Periodic checks of the O_2 sensors at the NSLS have been taken over by Payman Mortazavi, Senior Engineer. The new testing schedule is as follows:

- weekly check of O_2 sensor readings;
- monthly check of O_2 alarm level, accompanied by verification that fans turn on at concentrations below 0.195 and that alarm sounds in NSLS control room;
- quarterly calibration of O_2 sensors;
- yearly replacement of O_2 sensor.

Point 3.) The restriction for the LEGS target room (1-168) to dewars containing no more than 250 liters of liquid helium has been incorporated into the *Beam Line Safety Awareness* training for the LEGS (X-5) facility at the NSLS and signs indicating this restriction have been posted at the entrances to the room.

> In addition, please consider posting this restriction at the entry to
> the Target Room.
>
> Please review this input and provide a response to Ed Lessard and
> myself.
>
> Thank you!
> Rich Travis
> LESHC Secretary
>
>
>

Lessard, Edward T

From: Ellerkamp, John J
Sent: Tuesday, April 06, 2004 8:10 AM
To: Lessard, Edward T; Travis, Richard J
Cc: Sandorfi, Andrew; Hoey, Steven A
Subject: LEGS Quantum Cryostat Pressure Relief Valves/ Tests

Follow Up Flag: Follow up
Flag Status: Flagged

On April 2, I verified that the factory puchased valves were as per spec according to the maufacturer's markings, rated pressures on valves and the enclosed table and locations per gas flow schematic drawing 2004\P153\Block_48.dwg. I witnessed the successful testing of the highlighted adjustable relief valves as well.

Jack

LEGS relief Valve Table

Table 1 Relief Valves.

Table of Relief Valves		
Revised Apr 5/04		
Name of Relief Valve	Valve Setting	Location of the Relief Valve
S13	5 psig*	On valve above turbo-pumps
S14	1 psig*	Alcatel pump M151a exhaust
S15	1 psig*	Alcatel pump M151b exhaust
S10	5 psig*	After adsorber, on back of pump stand panel
S11	10 psig*	On gas cleaner
S11a	30 psig*	On gas cleaner
S12	10 psig*	On gas cleaner
S12a	30 psig*	On gas cleaner
S9	<0.1 psig	On cryostat
S7	15 psig	On He-3 return line, on back of flow panel (on side of cryostat)
SBY	15 psig	Bypass return relief, on back of flow panel (on side of cryostat)
S6	5 psig*	1K pot pump line, on top of cryostat
S16	5 psig*	2K pot pump line, on top of cryostat
S3b	1 psig*	Helium reservoir (at totalizer inlet), to maintain reservoir pressure
S3	4 psig	Helium recovery line, high capacity, on top of cryostat
SLN_2	10 psig*	LN_2 delivery line to cryostat, beside solenoid valve
SLN_2a	1 psig*	Cryostat LN_2 reservoir exhaust line
LN_2-supply	5 psig*	LN_2 supply line

* - Purchased valve, sat factory, NOT adjustable

Adjustable valve